Channel Quality Prediction And Localization

by

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A thesis submitted in the partial fulfillment of the requirements for the degree of
Master of Technology
in
Information and Communication Technology

Dhirubhai Ambani Institute of
Information and Communication Technology, Gandhinagar

May 2007

Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Information and Communication Technology at DA-IICT and has not been submitted elsewhere for a degree

ii) Due acknowledgement has been made in the text to all other material used.

Signature of Student

Certificate

This is to certify that the thesis work entitled *Channel Quality Prediction And Localization* has been carried out by *Animesh Patel (200511006)* for the degree of Master of Technology in Information and Communication Technology at this Institute under my supervision.

Prof. Naresh Jotwani
Thesis Supervisor

Abstract

In this thesis we focus on two problems, Channel Quality Prediction and Localization in wireless network.

In High-Speed Downlink Packet Access (HSDPA) architecture of Universal Mobile Telecommunications Services (UMTS), User Equipment (UE) provides Channel Quality Indicator (CQI) values to Node B (base station), as an indication of current channel quality. We investigate two methods for channel quality prediction, which can be implemented at Node B. Each of these method uses recent CQI values to predict future channel quality, i.e. future CQI values. Experiments are conducted in different environments, to check accuracy of these methods and found that the simple method using Least-Squares Line gives as good results as the complex method using Spline. Packet schedulers can be developed which uses predicted CQI values for scheduling.

Cellular networks are used for localization where the UEs are located by measuring the signal traveling to and from a set of fixed cellular base stations (Node B). We propose a Markov Chain Model, which can be used as supplement to Angle of Arrival (AOA) method which is used for localization. Sector-specific information with recent CQI values and information about angle of arrival of signal can be used to estimate UE's location using proposed model, in UMTS network supporting HSDPA architecture.

Acknowledgements

I would like to take this opportunity to acknowledge the unswerving efforts of my guide Prof. Naresh Jotwani during the tenure of this work. His luminous way of teaching and approaching different problems has been a memorable experience.

I would like to thank Prof. Suman Mitra and Prof. Manjunath Joshi for reviewing my thesis and providing helpful comments and suggestions.

I am indebted to Resource Center at DA-IICT and ACM Portal, and to the developers of CiteSeer and Google, who have changed the way of doing research.

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Chapter 1

Introduction

Since last decade demand of packet data services is growing enormously on wireless networks, and the applications are becoming more and more bandwidth consuming. In order to meet increasing demand of high data rates, especially in the downlink, 3rd Generation Partnership Project (3GPP) has introduced the concept of High-Speed Downlink Packet Access (HSDPA).

HSDPA standard[1] introduces a new logical channel that is shared among users of the sector[1]. Allocation of this shared channel to users is controlled by Packet Scheduler, located at Node B (Base station). The packet scheduler takes scheduling decision on different criterions like user's channel quality, Quality of Service (QoS) requirements etc.

At each Transmission Time Interval (TTI), the feedback of channel condition experienced by all UEs, is available in terms of Channel Quality Indicator (CQI) values at Node B. The scheduler uses these values to calculate the available data rate in the next TTI. To provide better system performance, channel quality of users is one of the main aspects to be considered.

[1]Area covered by Node B

UE calculates this CQI value based upon the current measured Signal to Noise Ratio (SNR) level and block error rate perceived. SNR level depends on several factors like free space loss, shadowing effect and small scale fading (multipath). Free space loss depends on distance between UE and Node B while other are caused by the objects cluttered in surrounding environment.

As mentioned above, the current packet schedulers take scheduling decisions based on the current CQI values available. The scheduling decision can be amended to improve system performance, if it is possible to forecast the channel conditions of UEs. The aim is to investigate method(s) that can be used to predict the CQI values that could be sent by the UE in future TTIs. These values can be used for scheduling to provide better QoS assurances.

The other interesting problem is to estimate the location of a UE in the given cell. We propose a model for localization which uses sector-specific information with angle of arrival information and CQI values to estimate the location of UE. This location information can be used for applications like resource management, fleet management, etc.

1.1 Organization of Thesis

The rest of this thesis is organized as:
Chapter 2: explains concepts & features of HSDPA standard.
Chapter 3: discusses about two methods of channel quality prediction & presents the results for both methods in different environments.
Chapter 4: starts with a short introduction of localization and then proposes a model for localization using Markov chain.
Chapter 5: draws conclusion of this thesis with future work possible.

Chapter 2

High Speed Downlink Packet Access

In order to meet the increasing demand for high data-rate multimedia services, the 3rd Generation Partnership Project (3GPP) had released a new high-speed data transfer feature named High-Speed Downlink Packet Access (HSDPA). HSDPA standard is designed to increase data throughput in downlink by means of fast link adaptation and fast physical layer (L1) retransmission [2, 3]. The standard includes features such as Adaptive Modulation and Coding (AMC), shorter Transmission Time Interval (TTI) of 2ms, and fast layer 1 retransmission using hybrid ARQ (HARQ) techniques. It provides peak data rates up to 10 Mbps.

The basic operation of HSDPA is shown in figure 2.1. User Equipment (UE) sends its downlink channel quality feedback to Node B (base station) in the form of Channel Quality Indicator (CQI). CQI for the next TTI is selected based on current SNR level and block error measured while decoding the current frame. Node B extracts CQI sent by each UE in uplink and uses a CQI mapping table to decide transport block format i.e. transport block size, number of parallel codes, modulation, and reference power adjustments. CQI values range from 0 to 30, where 0 indicates that the UE is

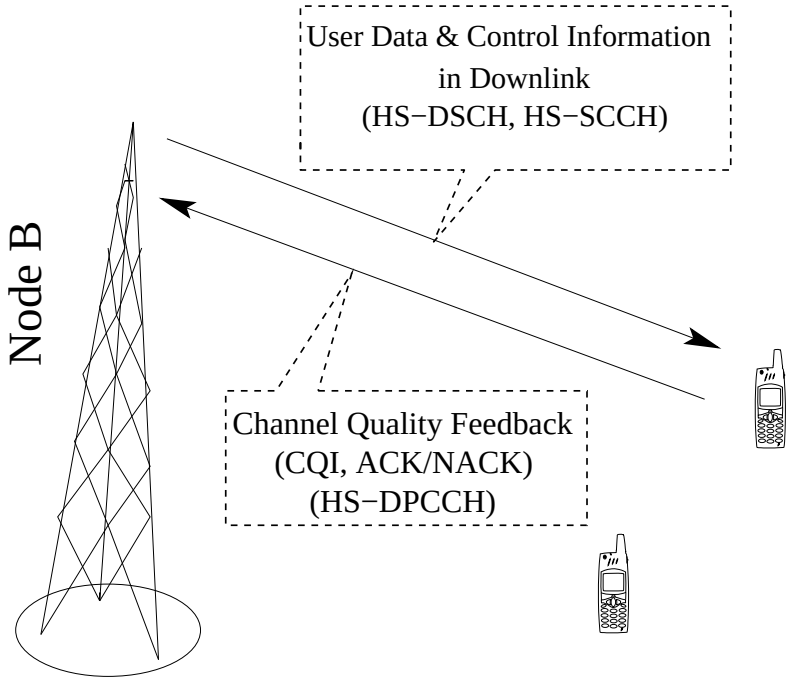

Figure 2.1: Basic Operations of HSDPA

out of reach, possibly having moved in the range of another Node B and 30 indicates that UE experiences best channel quality.

2.1 HSDPA Concept

Two key channels are introduced in downlink to support HSDPA: HS-DSCH (High-Speed Downlink Shared Channel) for data and HS-SCCH (High-Speed Shared Control Channel) for control, while one channel HS-DPCCH (High-Speed Dedicated Physical Control Channel) is introduced in uplink for channel quality feedback[3]. HS-DSCH resources are shared among all users in a particular sector. The primary channel multiplexing occurs in the time domain, where each TTI consists of 2 ms. The TTI has been reduced to achieve short round trip delay between the UE and the Node B, and improve the link adaptation rate and efficiency of the AMC.

The HS-SCCH is a fixed rate channel used for carrying downlink signaling between

the Node B and the UE before the beginning of each scheduled TTI. This includes the UE's identity, HARQ related information and the parameters of the HS-DSCH transport format selected by the link adaptation mechanism.

The HS-DPCCH carries ACK/NACK signaling indicating whether the corresponding downlink transmission was successfully decoded, as well as a Channel Quality Indicator to be used for the purpose of link adaptation. The CQI is used to estimate the transport block size, modulation type and number of channelization codes that can be supported at a given reliability level in case of a downlink transmission.

The key idea of the HSDPA concept is to increase packet data throughput with methods like link adaptation and fast physical layer (L1) retransmission. For achieving these, MAC (Medium Access Control) layer is distributed between RNC (Radio Network Controller) and Node B in HSDPA. MAC-hs performs HSDPA related functions which is placed in Node B as shown in figure 2.2. The packet scheduler is also placed in Node B to take advantage of fast link adaptation techniques as shown in figure 2.2.

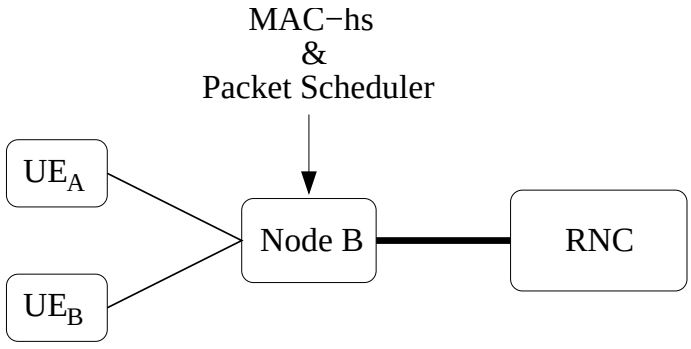

Figure 2.2: Position of MAC-hs & Packet Scheduler in HSDPA Architecture

2.2 Features of HSDPA

Main features of HSDPA are as follows[2]:

- **Link Adaptation:** The process of modifying the transmission parameters to compensate for the variations in channel conditions is known as link adaptation. AMC is a technique used for link adaptation in HSDPA.

- **Adaptive Modulation and Coding (AMC):** Adaptive Modulation and Coding (AMC) is a fundamental feature of HSDPA. It consists of continuously optimizing the code rate, the modulation scheme, the number of codes employed and the transmit power per code based on the channel quality reported (CQI Feedback) by the UE. In order to achieve very high data rate, HSDPA adds a higher order modulation (16QAM) with the existing QPSK modulation. UE experiencing more favorable channel condition (i.e. near to Node B) will be allocated higher data rates.

- **Fast Scheduling:** The scheduler is a key element of HSDPA that determines the overall behavior of the system and, to a certain extent, its performance. For each TTI, it determines which UE (or UEs) the HS-DSCH should be transmitted to and, in conjunction with the AMC, at which data rate. One important change from R'99 channels is that the scheduler is located at the Node B as opposed to the RNC. In conjunction with the short TTI (2 ms) and the CQI feedback, this enables the scheduler to quickly track the UE channel condition and adapt the data rate allocation accordingly.

- **HARQ & Fast Retransmission:** The retransmission mechanism selected for HSDPA is Hybrid Automatic Repeat Request (HARQ). HARQ allows the UE to rapidly request retransmission of erroneous transport blocks until they are successfully received. HARQ functionality is implemented at the MAC-hs (Media Access Control high speed) layer, which is terminated at the Node B, as opposed to the RLC, which is terminated at the S-RNC (Serving-RNC).

Therefore the retransmission delay in HSDPA is much lower then for WCDMA R'99 (Wideband Code Division Multiple Access Release '99).

Chapter 3

Channel Quality Prediction

In wireless communication, mobile radio channel is used to transmit information. The mobile radio channel places fundamental limitation on the performance of wireless communication. The transmission path between the transmitter and the receiver can vary from simple line-of-sight (LOS) to one that is severely obstructed by buildings, mountains and foliage. Unlike wired channels that are stationary and predictable, radio channels are extremely random and do not offer easy analysis.

3.1 Radio Wave Propagation

The mechanism behind electromagnetic wave propagation can generally be attributed to LOS, reflection, diffraction and scattering. Due to multiple reflections from various objects, the electromagnetic waves (signals) travel along different paths of varying lengths. The interaction between these waves causes multipath fading, at a specific location, and the strengths of the waves decrease as the distance between the transmitter and receiver increases.[4]

3.1.1 Factors Affecting Signal Quality

Some factors affect signal quality, like environment, geographic situations, UE's speed, distance between Node B and UE, etc. Overall effect of all these factors can be divided in two types, large-scale path losses and small-scale fading.

Large-Scale Path Losses[4] Large-scale path losses are due to two types of losses:

- **Free space loss:** Free space loss is the result of attenuation of transmitted signal, depending only on frequency and distance traveled, disregarding all the variable factors like, reflection, diffraction, absorption, etc. So, free space loss is loss in line-of-sight communication and is proportional to $1/d^2$, where d indicates distance traveled.

- **Shadowing:** The attenuation of the signal caused by obstructions in the propagation path is called shadowing. Free space loss does not consider the fact that the objects in surrounding environment obstruct the signal and in most of the cases LOS communication is not possible. Signal reaches to the receiver after many reflections and diffractions. This leads to measured losses at receiver which vary vastly than the average value predicted by free space loss.

Small-Scale Fading[4] Small-scale fading is due to multipath effect.

- **Multipath:** Multipath is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times. The effects of multipath include constructive and destructive interferences. Multipath causes rapid changes in received signal strength.

3.2 Channel Quality Indicator

In HSDPA, channel quality measure available at Node B is CQI value. CQI values are calculated and transmitted by UE at every TTI. CQI value for next TTI is selected

based on current SNR (Signal-to-Noise Ratio) level and block error measured while decoding the current frame[5]. Node B extracts CQI sent by each UE in uplink and uses a CQI mapping table to decide transport block format i.e. transport block size, number of parallel codes, modulation, and reference power adjustments.

As mentioned above, free space loss, shadowing and multipath fading affect the transmitted signal. So, CQI value is also affected by these factors. One sample of such CQI trace is shown in figure 3.1. This trace is generated using EURANE (Enhanced UMTS Radio Access Network Extensions for ns-2) (Appendix B).

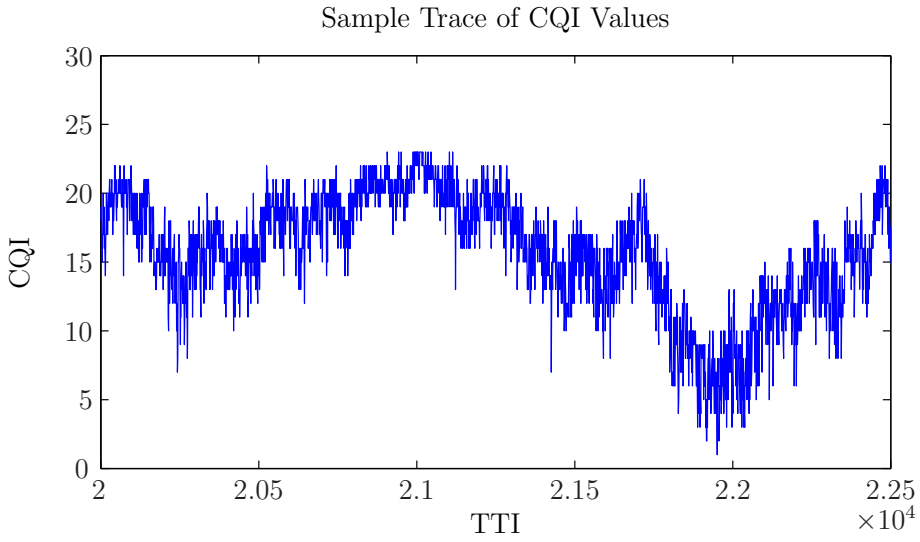

Figure 3.1: Sample of CQI Values

In figure 3.1, slow and fast variations in CQI values are clearly visible. Fast variations are due to small-scale fading (multipath) and slow variation are due to large-scale path losses.

Figure 3.2 shows, one more CQI trace which is generated by carefully amending the module of EURANE, which generate CQI values by simulating physical channel, to show effect of multipath and free space loss on CQI values by removing shadowing

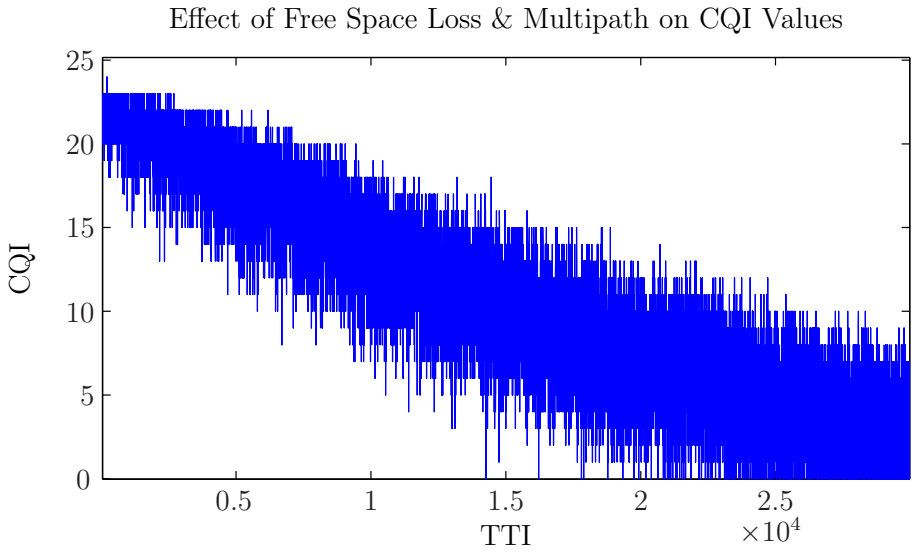

Figure 3.2: Effect of Free Space Loss & Multipath on CQI Values

effect and moving the UE away from Node B with constant speed. As UE is moving away from Node B, CQI values are decreasing due to free space loss. Fast variations are due to multipath effect and slow variations are not present as shadowing is not present. Slow variations will increase as shadowing increases.

3.3 Predicting CQI

Now, the aim is, to predict channel quality from current channel quality information, i.e. to predict future CQI values from latest and past CQI values. As shown in the figure 3.3, let the latest CQI value, C_r, available at Node B comes at r^{th} TTI. Here recent m CQI values from C_{r-m+1} to C_r are used to predict future n CQI values from C_{r+1} to C_{r+n}.

Different curve fitting methods can be applied to these m CQI values to catch overall change in CQI values over past m TTIs and then extrapolation technique can be used to get the CQI values for next n TTIs. Here two different curve fitting methods, Least-Squares Line and Spline, are applied.

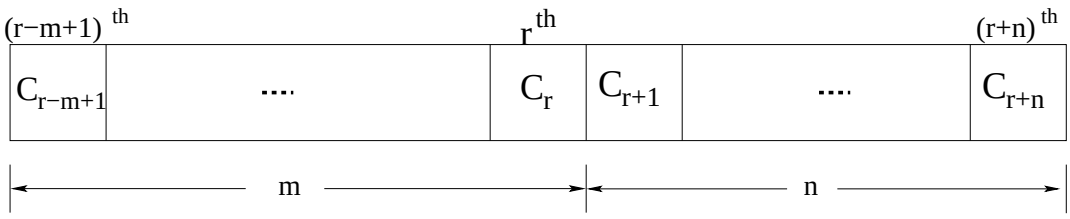

Figure 3.3: Prediction of CQI Values

3.3.1 Least-Squares Line

As described above, multipath causes fast variations and large-scale losses causes slow vatiations in CQI values. Effect of multipath is random and so can not be predicted. Due to this, fast variations should be removed from prediction process and this will cause no wrong effect on prediction. So, prediction should be applied on CQI values, affected by only large-scale path losses and predicted values also neglect multipath.

Here least-squares line method can be used to find a line $y = Ax + B$ as explained in Appendix A, which has a least mean square error with the actual m CQI values. This line shows how the overall change in CQI values due to large-scale path losses only by removing fast variation from available CQI values. Now, find out the values of $y_i = Ax_i + B,\ for\ i = r+1, r+2, \cdots, r+n$. Rounding of the values of y_i gives how the CQI values may change in next n TTIs, i.e. predicted CQI values from C_{r+1} to C_{r+n}. These predicted values do not show effect of multipath.

3.3.2 Spline

To predict next CQI values from the past m values, if extrapolation technique that uses polynomial curve fitting is used, it gives wrong results, as small-scale fading causes much variations in CQI values. The resulting polynomial wiggle in order to pass through these points. As a result extrapolation on that polynomial is not possible.

As discussed in Least-Squares Line method, effect of multipath should be removed or at least reduced from available CQI values. For reducing the fast variations (multipath) moving average over some previous values should be taken so the positive and negative variations will negate each other and fast variations will be reduced. For k^{th} TTI, moving average on w values can be calculated using following equation,

$$C'_k = \frac{1}{w} \sum_{i=k-w+1}^{k} C_i$$

Moving average should be calculated for CQI values from C_{r-m+w} to C_r. Now, curve fitting method can be applied to these processed data $\{C'_k\}_{r-m+w}^{r}$ and then extrapolation can be used to get next CQI values.

Cubic spline method can be applied to these moving averages of CQI values to predict future CQI values. After reducing fast variations, the curve is not sufficiently smooth. As spline uses last four points to evaluate last piece of polynomial which is going to be extrapolated, if one of the point is diverged from others, then extrapolation of this resulting polynomial gives unsatisfactory results. This happens many times if curve is not sufficiently smoothed. To make the curve smooth, moving average should be taken on large number of values. But as we increase the number, i.e. as average is taken over more values, we also reduce the effect of large-scale path losses, which is not desirable.

To solve this problem, two stage moving average should be taken, i.e. take a moving average on w_1 values of C_k, to get C'_k and then take moving average on w_2 values of C'_k to get C''_k. And then instead of taking continuous points to generate spline curve, take points at some interval.

For curve fitting, spline method can be applied to these processed data as explained in Appendix A, to get a spline function $S(x)$. Now, extrapolation is applied to spline

$S(x)$ to calculate values at $S(k),\ for\ k = r+1, r+2, \cdots, r+n$. Rounding of this values gives predicted CQI values, C_{r+1} to C_{r+n}, for next n TTIs from $r+1$ to $r+n$.

3.4 Results

In this section, results of both prediction methods in different environments, which are simulated as a part of EURANE's physical channel simulator module, are discussed.

Among these, pedestrian and vehicular environments, simulate the effect of UE's speed on CQI values. Speed of UE, in pedestrian environment should be in range from 3 to 15 KMPH and in vehicular environment, should be in range from 50 to 500 KMPH.

Other three environments, rural, urban and hilly terrain, simulate the effect of different types of operational geographical areas on CQI values. As there names indicate, these environments simulate rural area, urban area and hilly terrain, respectively.

All these environments use different power delay profiles[1] to simulate multipath effect in different environments and shadowing effect is simulated using random numbers which are normally distributed with mean 0 and standard deviation is needed to set according environment.

For all the results, prediction interval of 10 CQI values is chosen, i.e. 10 CQI values are predicted from previous CQI values. All results are taken for 100,000 TTIs, i.e. 200 seconds.

[1]**Power Delay Profile:** The power delay profile shows the arrival times, in nanoseconds, of different versions of the signal versus its received power in dBm between the selected transmitter and the selected receiver. The times are given relative to the arrival time of the line-of-sight, i.e., if the line-of-sight path exists, its arrival time is 0.0

Figure 3.4 shows comparison of real and predicted CQI values for Pedestrian environment having standard deviation of shadowing equals to 8.

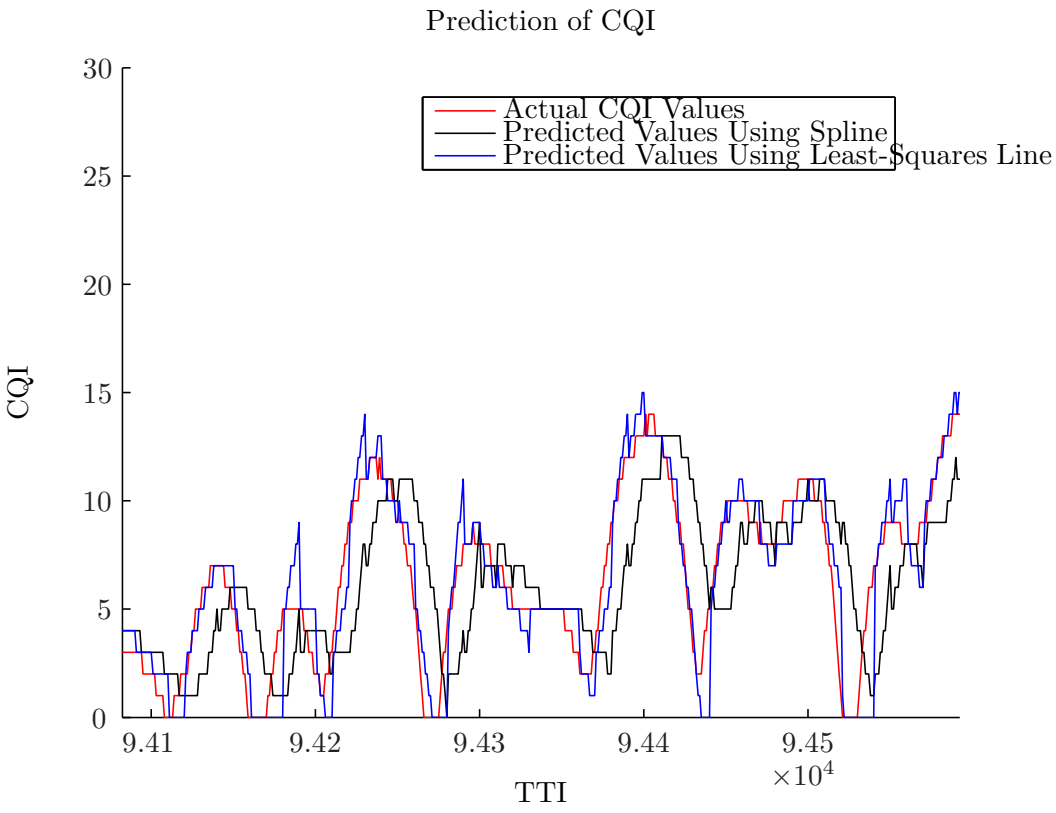

Figure 3.4: Sample of CQI values and Predicted CQI Values Using Both Methods for Pedestrian Environment

Following each subsection contains, two histograms showing error in prediction in both methods, a table containing results and discussion about the result.

3.4.1 Pedestrian Environment

Here results for pedestrian environment having standard deviation of shadowing set to 8 and speed of UE set to 3 KMPH are shown. For prediction method using Least-Squares Line, latest 5 CQI values are used to evaluate the line equation. For

prediction method using Spline, two stage moving average over 10 and 5 CQI values for first and second stage respectively, is taken over past CQI values. Then spline function over interval of 5 points is evaluated.

As UE's speed is only 3 KMPH, it hardly changes its position in one TTI duration. Fast variations due to multipath become slower as change in position of UE is very slow and CQI values remain same for few TTIs and whenever change occurs, it changes by 1 or 2 CQI values only, for most of the time. Using these characteristics pedestrian UEs can be distinguished from vehicular ones.

As variation in CQI values are slower, these variations are predictable using least-squares line or spline fitted over small number of CQI values and gives good results.

Figure 3.5 shows two histograms, for the error in prediction of CQI values, for each method. Table I gives, the percentage of predicted CQI values, having zero error, error in range [-1,1], [-2,2] and [-3,3] CQI values. Mean error and mean square error for both methods are also given.

	Using Least-Squares Line	**Using Spline**
Zero Error (in %)	45.24	28.54
Error in Range $[-1, 1]$ (in %)	79.68	60.82
Error in Range $[-2, 2]$ (in %)	91.10	79.30
Error in Range $[-3, 3]$ (in %)	95.52	88.47
Mean Error	0.966	1.644
Mean Square Error	2.988	6.643

Table I: Pedestrian Environment having Standard Deviation of Shadowing = 8

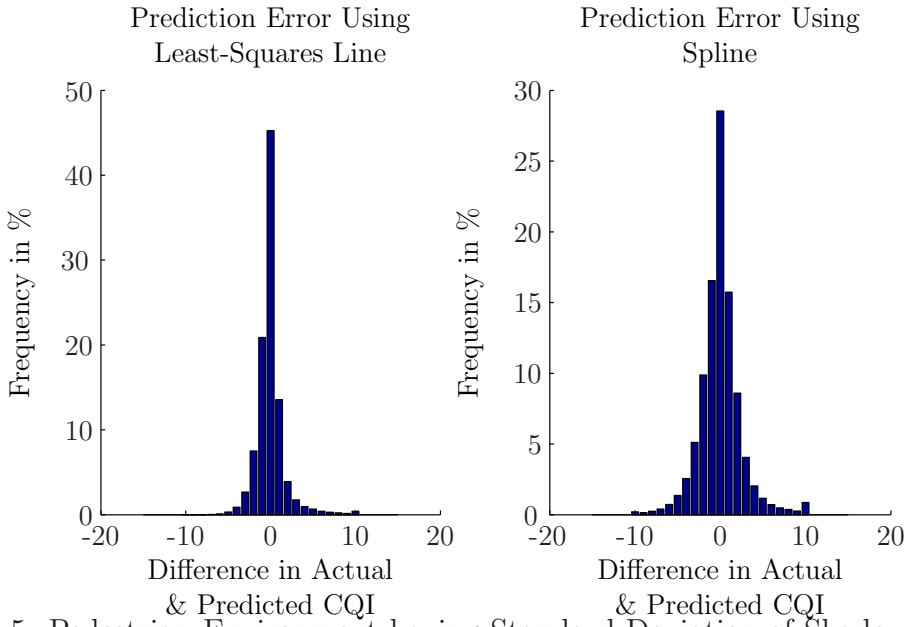

Figure 3.5: Pedestrian Environment having Standard Deviation of Shadowing = 8

3.4.2 Vehicular Environment

Here results for vehicular environment having standard deviation of shadowing set to 1 and speed of UE set to 120 KMPH are shown. For prediction method using Least-Squares Line, latest 60 CQI values are used to evaluate the line equation. For prediction method using Spline, two stage moving average over 60 and 40 CQI values for first and second stage respectively, is taken over past CQI values. Then spline function over interval of 20 points is evaluated.

As UE is moving at high speed, multipath effect is high. And standard deviation of shadowing is chosen low, so frequency of slow variations in CQI values, due to shadowing, become lower, as explained in section 3.2. To reduce the fast variations, curve fittings over more CQI values are taken and gives good results, as fast variations are reduced more, without loss of information about slow variations.

Histograms are shown in figure 3.6 and table II shows results.

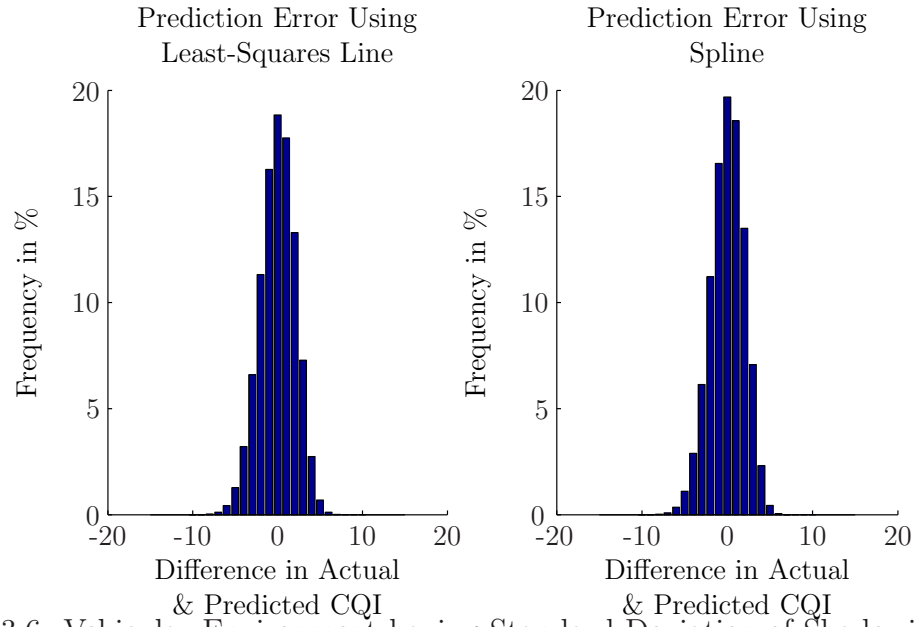

Figure 3.6: Vehicular Environment having Standard Deviation of Shadowing = 1

	Using Least-Squares Line	**Using Spline**
Zero Error (in %)	18.84	19.68
Error in Range $[-1, 1]$ (in %)	52.87	54.81
Error in Range $[-2, 2]$ (in %)	77.49	79.53
Error in Range $[-3, 3]$ (in %)	91.37	92.74
Mean Error	1.631	1.560
Mean Square Error	4.307	3.955

Table II: Vehicular Environment having Standard Deviation of Shadowing = 1

Here results for vehicular environment having standard deviation of shadowing set to 8 and speed of UE set to 120 KMPH are shown. For prediction method using Least-Squares Line, latest 40 CQI values are used to evaluate the line equation. For prediction method using Spline, two stage moving average over 30 and 15 CQI values for first and second stage respectively, is taken over past CQI values. Then spline function over interval of 20 points is evaluated.

In this case, shadowing effect is higher as standard deviation is set to 8. As explain in section 3.2, slow variations are increased due to high shadowing effect. And multipath effect is also high as UE is moving at high speed. As slow variations are more frequent, curve fitting over large number of CQI values causes loss of information about shadowing. So, curve fittings over small number of CQI values have been done to reduce fast variations without loosing shadowing information.

Histograms are shown in figure 3.7 and table III shows results.

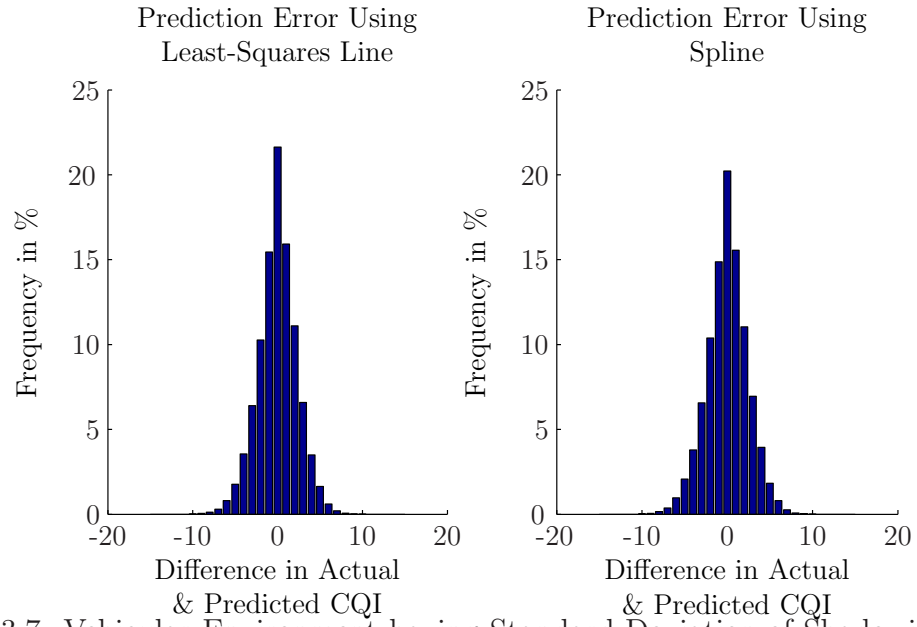

Figure 3.7: Vehicular Environment having Standard Deviation of Shadowing = 8

	Using Least-Squares Line	**Using Spline**
Zero Error (in %)	21.63	20.23
Error in Range $[-1, 1]$ (in %)	52.99	50.66
Error in Range $[-2, 2]$ (in %)	74.36	72.08
Error in Range $[-3, 3]$ (in %)	87.36	85.59
Mean Error	1.726	1.824
Mean Square Error	5.264	5.801

Table III: Vehicular Environment having Standard Deviation of Shadowing = 8

3.4.3 Rural Environment

Here results for rural environment having standard deviation of shadowing set to 4 and speed of UE set to 120 KMPH are shown. For prediction method using Least-Squares Line, latest 60 CQI values are used to evaluate the line equation. For prediction method using Spline, two stage moving average over 40 and 20 CQI values for first and second stage respectively, is taken over past CQI values. Then spline function over interval of 20 points is evaluated.

Again, high speed of UE causes fast variations. As the standard deviation of shadowing is set to 4, for rural environment, frequency of slower variations is lower then previous case, which has standard deviation of shadowing equals to 8. So, curve fitting over few more values are taken and give good results.

Histograms are shown in figure 3.8 and table IV shows results.

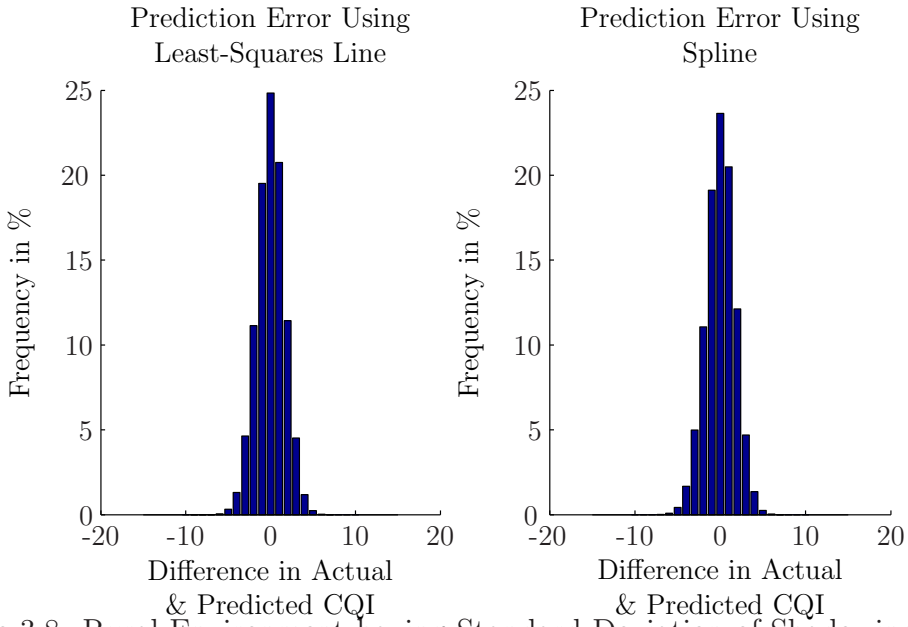

Figure 3.8: Rural Environment having Standard Deviation of Shadowing = 4

	Using Least-Squares Line	**Using Spline**
Zero Error (in %)	24.85	23.65
Error in Range $[-1, 1]$ (in %)	65.11	63.26
Error in Range $[-2, 2]$ (in %)	87.68	86.46
Error in Range $[-3, 3]$ (in %)	96.83	96.14
Mean Error	1.263	1.315
Mean Square Error	2.710	2.905

Table IV: Rural Environment having Standard Deviation of Shadowing = 4

3.4.4 Urban Environment

Here results for urban environment having standard deviation shadowing set to 8 and speed of UE set to 50 KMPH are shown. For prediction method using Least-Squares Line, latest 50 CQI values are used to evaluate the line equation. For prediction method using Spline, two stage moving average over 30 and 15 CQI values for first and second stage respectively, is taken over past CQI values. Then spline function over interval of 20 points is evaluated.

Many buildings in urban area, severally obstruct the transmitted signal, which cause high shadowing effect. In addition, multiple versions of transmitted signal,

reach to the UE, which cause high multipath effect. As frequency of slow variations is higher, due to higher shadowing, curve fittings over small number of CQI values have been done and work better.

Histograms are shown in figure 3.9 and table V shows results.

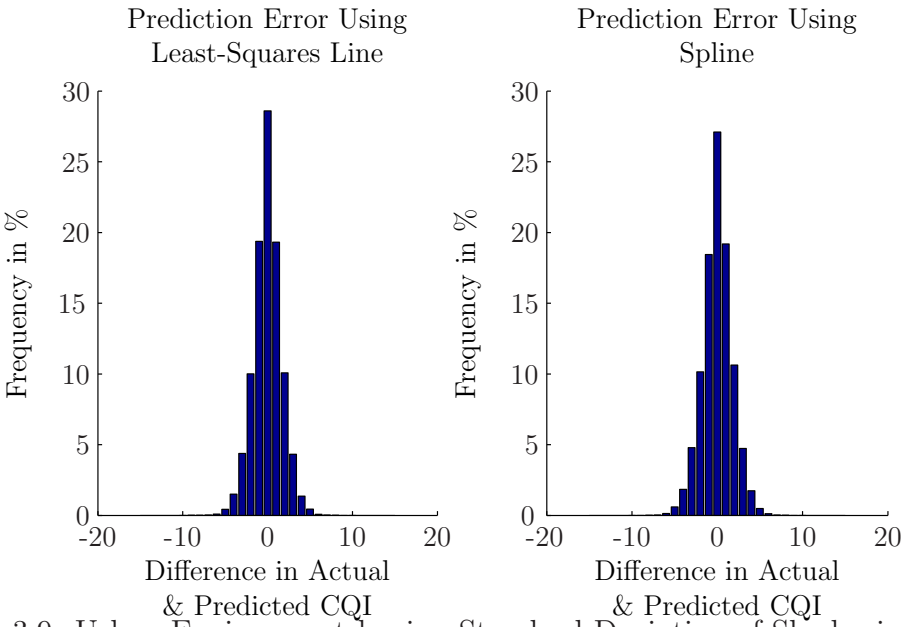

Figure 3.9: Urban Environment having Standard Deviation of Shadowing = 8

	Using Least-Squares Line	**Using Spline**
Zero Error (in %)	28.60	27.09
Error in Range $[-1, 1]$ (in %)	67.28	64.73
Error in Range $[-2, 2]$ (in %)	87.37	85.51
Error in Range $[-3, 3]$ (in %)	96.06	95.02
Mean Error	1.220	1.294
Mean Square Error	2.730	3.027

Table V: Urban Environment having Standard Deviation of Shadowing = 8

3.4.5 Hilly Terrain

Here results for hilly terrain having standard deviation shadowing set to 8 and speed of UE set to 120 KMPH are shown. For prediction method using Least-Squares Line, latest 40 CQI values are used to evaluate the line equation. For prediction method using Spline, two stage moving average over 30 and 15 CQI values for first and second stage respectively, is taken over past CQI values. Then spline function over interval of 20 points is evaluated.

Hills in the operational geographical area, cause high shadowing and multipath effects, same as buildings cause in urban area. So, curve fittings over small number of CQI values have been done and work better.

Histograms are shown in figure 3.10 and table VI shows results.

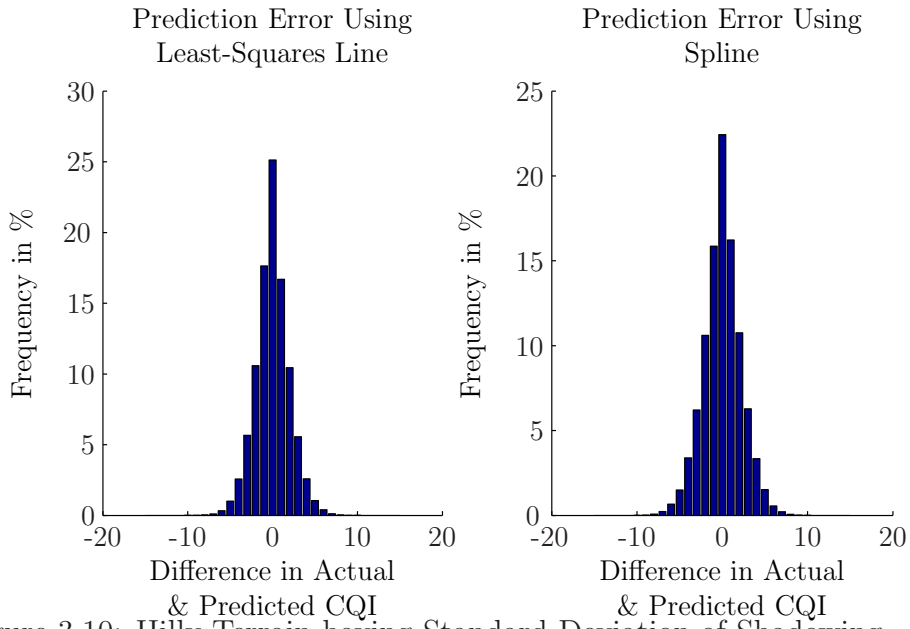

Figure 3.10: Hilly Terrain having Standard Deviation of Shadowing = 8

	Using Least-Squares Line	**Using Spline**
Zero Error (in %)	25.13	22.43
Error in Range $[-1, 1]$ (in %)	59.46	54.51
Error in Range $[-2, 2]$ (in %)	80.49	75.87
Error in Range $[-3, 3]$ (in %)	91.72	88.37
Mean Error	1.478	1.665
Mean Square Error	3.980	4.934

Table VI: Hilly Terrain having Standard Deviation of Shadowing = 8

3.5 Benefit of Prediction

As discussed earlier, CQI value is used to decide transport block format for the next packet to be sent. In addition to this, packet scheduler decides, which user is to be scheduled in the next TTI. There are many different algorithms which are used for scheduling, like Round Robin (RR), Maximum CIR (Max C/I), Proportional Fair (PF)[6].

Round Robin (RR) This scheduling algorithm schedules UEs in round robin manner. So, this algorithm is fair to all UEs, without considering their channel condition. In this scheduling, no attempt is maid to increase system throughput.

Maximum Carrier-to-Interference Power Ratio (Maximum CIR) This scheduling algorithm schedules UE having highest CQI value in current TTI. This algorithm gives highest channel utilization but very unfair with the UEs who experience the bad channel condition for most of the time. Such UEs fill starvation as they are not able to access channel.

Proportional Fair (PF) This scheduling algorithm schedules UEs having good channel more frequently then the UEs having bad channel condition. So, this algorithm tries to achieve users level fairness while provides good channel utilization.

All these algorithms uses latest CQI values to schedule user for next TTI. Now, if scheduler at Node B knows what should be the CQI values in future, then better scheduling can be done on the basis of these future CQI values. These future CQI values can be predicted using any of the method discussed above. As scheduler knows whose CQI value is going low and whose going high, scheduling based on this information helps to increase channel utilization without being unfair.

3.5.1 Example

Let's assume that, there are two UEs, UE_A and UE_B, having same QoS requirements, in the sector. The prediction at r^{th} TTI says that CQI value of UE_A is going low while CQI value of UE_B is going high, as time progresses, as shown in table VII.

TTI	$r+1$	$r+2$	$r+3$	$r+4$	$r+5$	$r+6$	$r+7$	$r+8$	$r+9$	$r+10$
UE_A	21	20	20	19	19	18	18	17	17	16
UE_B	18	18	18	19	19	19	19	20	20	20

Table VII: Predicted CQI values for UE_A and UE_B

Actual CQI values send by UEs in next 10 TTIs from $r+1$ to $r+10$ are shown in table VIII

TTI	$r+1$	$r+2$	$r+3$	$r+4$	$r+5$	$r+6$	$r+7$	$r+8$	$r+9$	$r+10$
UE_A	21	20	22	22	20	21	16	20	20	18
UE_B	18	17	18	21	21	20	21	20	19	21

Table VIII: Actual CQI values sent by UE_A and UE_B

As prediction information is available to scheduler, it will schedule UE_A for first few TTIs and then schedule UE_B. Such scheduling can increase channel utilization as data will be sent to both UEs when their channel conditions will relatively better, and it is fair to both UEs as both will get channel.

Let's assume that we have modified PF scheduling algorithm, which uses predicted CQI values for scheduling. Comparison of current PF algorithm with this modified

	Current PF		**Modified PF**	
TTI	Scheduled UE	Data Rate (kbps)	Scheduled UE	Data Rate (kbps)
r+1	A	3040	A	3040
r+2	A	2720	A	2720
r+3	B	2080	A	3360
r+4	A	3360	A	3360
r+5	B	3040	A	2720
r+6	B	2720	B	2720
r+7	B	3040	B	3040
r+8	A	2720	B	2720
r+9	B	2400	B	2400
r+10	A	2080	B	3040

Table IX: Comparison of Current PF with Modified PF

PF algorithm is shown in table IX. One possible scheduling for current PF scheduler is shown in table. As current PF schedules the UE having better channel condition more frequently, it schedules UE_A for more time in initial TTIs and schedules UE_B for more time in later TTIs. While modified PF schedules UE_A for first half and UE_B for second half.

For both algorithms, available data rate (in kbps)[7] depending on CQI value, for each TTI is given. Current PF gives average data rate of 2720 kbps for TTIs from $r + 1$ to $r + 10$ and modified PF gives average data rate of 2921 kbps. So, use of predicted future CQI values for scheduling can increase system performance without being unfair.

Chapter 4

Localization

Localization in wireless networks is a process of estimating location of a user equipment using some location estimation system. The basic function of a location system is to gather information about the position of a UE operating in a geographical area and process that information to form a location estimate. A popular approach, known as radiolocation[8], measures parameters of signals that travel between an UE and a set of transceivers, which are subsequently used to derive the location estimate.

Many existing wireless location systems, such as the Global Positioning System (GPS) and Loran C, make use of radiolocation techniques. With these technologies the UE formulates its own position, which can be relayed to a central site. As another approach, cellular networks can be used for localization, where the UEs are located by measuring the signals traveling to and from a set of fixed cellular base stations (BSs). The signal measurements are used to determine the length and/or direction of the individual radio paths, and then the UE position is computed from geometric relationships.

In some localization methods, the UE uses signals transmitted by the fixed transceivers to calculate its own position, as in GPS, UE uses signals transmitted by three or more GPS satellites to calculate its own position. As another approach, BSs measure the

signals transmitted by the UE and send these information to some central site to estimate location. This approach has advantages over previous one that it can be implemented with low cost, on existing cellular networks with only few modifications in BS and no modifications in the UE. So, large pool of UEs already in use can be accommodated.

4.1 Applications of Localization in Wireless Networks

The potential applications of localization using cellular networks are[8]:

Emergency Calls Location information for wireless emergency calls permits rapid response in situations where callers are unable to tell their location.

Location-Sensitive Billing Location-sensitive billing provides a wireless carrier the ability to offer different rates depending on where the wireless terminal is used.

Fraud Detection Without the use of wireless location systems, it is very difficult to find and catch the cellular phone fraud.

Cellular System Design and Resource Management Location technology could also be used in wireless system design and for radio resource and mobility management. With the ability to locate a wireless call, system planners could improve their ability to architect cells and wireless systems. Cells could be better positioned and tuned, and spectral efficiency improved. More effective resource management could be obtained through the allocation of channels based on the knowledge of the wireless caller's location.

Fleet management and intelligent transportation systems (ITS) Wireless location technology is also useful for fleet operations. Many fleet operators already

make use of location technology to track their vehicles and operate their fleets more efficiently, thus improving their field service. Police and emergency vehicles, as well as taxi and other service operators, could also improve their field service through the use of location technology. Having knowledge of the location of their vehicles allows a dispatcher to locate the nearest available vehicle, greatly improving response times.

4.2 Methods of Localization (Radiolocation)

Radiolocation systems can be implemented that are based on either signal strength, angle of arrival (AOA), or time of arrival (TOA) measurements, or their combinations. The signal measurements are used to determine the length or direction of the radio paths to/from an UE from/to multiple BSs.[8]

4.2.1 Signal Strength

Radiolocation using signal strength is a well known location method that uses a known mathematical model describing the path loss attenuation with distance. Since a measurement of signal strength provides a distance estimate between the UE and BS, the UE must lie on a circle centered at the BS. By using multiple BSs, the location of the UE can be determined. Multipath and shadowing effects are the sources of error in this method.

4.2.2 Angle of Arrival

Angle of Arrival[9] techniques estimate the UE location by first measuring the AOAs of signals from the UE at several BSs through the use of antenna arrays. Scattering near and around the UE and BS will alter the measured AOA. In the absence of an Line of Sight (LOS) signal component, the antenna array will lock on to a reflected signal that may not be coming from the direction of the UE. Even if an LOS component is present, multipath will still interfere with the angle measurement. The accuracy of

the AOA method diminishes with increasing distance between the UE and BS due to fundamental limitations of the devices used to measure the arrival angles as well as changing scattering characteristics.

4.2.3 Time of Arrival

The final class of radiolocation techniques are those based on estimating the TOAs[9] of the signals transmitted by the UE and received at multiple BSs or the time differences of arrivals (TDOAs) of the signals received at multiple pairs of BSs. In the TOA approach, the distance between an UE and a BS is measured by finding the one-way propagation time between an UE and a BS. In the TDOA approach, differences in the TOAs are used. The essential ingredient for the time based approaches are high-resolution timing measurements. However, it should be noted that LOS propagation conditions are still necessary to achieve high accuracy for the time-based methods.

4.3 Proposed Method for Localization

As described in chapter 2 & chapter 3, in HSDPA each UE sends CQI values at every 2 ms to Node B and angle of arrival of signal can be calculated using antenna arrays. CQI values with angle of arrival information should be used for location estimate. It is possible to estimate position of a UE by using these information as evidence. For that proper Bayesian Network (BN)[10] need to be constructed. In addition to these evidence, current location also depends on previous location. So, a Markov chain model[10] can be constructed using these evidence and previous location information.

Next section explains construction of Bayesian Network and how inference should be done using evidence. Then section 4.5 explain construction of Markov chain and how location will be estimated using that.

4.4 Constructing Bayesian Network

To construct the Bayesian network first task is to identify possible nodes or variables[1] and put them in correct order to decide proper topology such that the "root cause" nodes i.e. nodes that represent the cause, should come first and then nodes influenced by them. Next there Conditional Probability Tables (CPTs)[10] should be calculated.

4.4.1 Identifying Nodes

In HSDPA, CQI values are available and angle can be measured using angle of arrival technique. These two parameters should be used as evidences to estimate probable location, so these CQI values, measured angle and estimated location are three possible variables/nodes and are represented using CQI, MA, and L respectively.

As AOA technique may give error in measured angle due to multipath and scattering near UE or Node B, actual direction of UE can be different then measured angle (MA). For good location estimation, all possible directions in which UE can be located should be considered and these possible directions in terms of angle is denoted by A. The probability of UE in any direction depends on the measured angle using AOA.

Finally, four possible nodes for this BN are MA, A, L and CQI.

4.4.2 Deciding Topology of Bayesian Network

Now, MA is measured by antenna arrays so is not dependent on any other variable and so becomes "root cause". Probable direction of UE, A is depend on measured angle MA, so A becomes child node of MA. Location can be given as distance of UE from Node B for given direction of UE. So location L depends on direction A.

[1] **Node** and **variable** are used as synonym.

And finally, CQI value CQI depends on location L. Resulting topology of Bayesian Network is shown on figure 4.1.

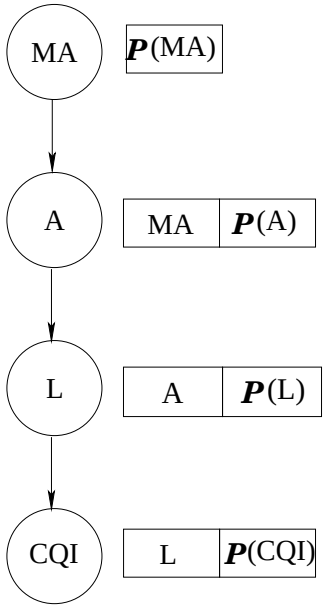

Figure 4.1: Topology of Bayesian Network

4.4.3 Conditional Probability Tables

For inferring location using this BN we need to estimate three CPTs, $\mathbb{P}^2(A/MA)$, $\mathbb{P}(L/A)$ and $\mathbb{P}(CQI/L)$. These CPTs can be estimated by taking sufficient number of samples from real world.

For a given sector, CQI values at every location can empirically be measured. Studies shows that most of the mobile UEs are moving on highways, roads and pathways. And most of the static UEs are at offices or homes. So, these samples should be taken at all such possible places. By analyzing these empirically collected data CPTs can be estimated.

[2] $\mathbb{P}(X)$ denotes a vector of values for probabilities of each possible value of variable X, while $P(x)$ denotes single value for probability of $X = x$.

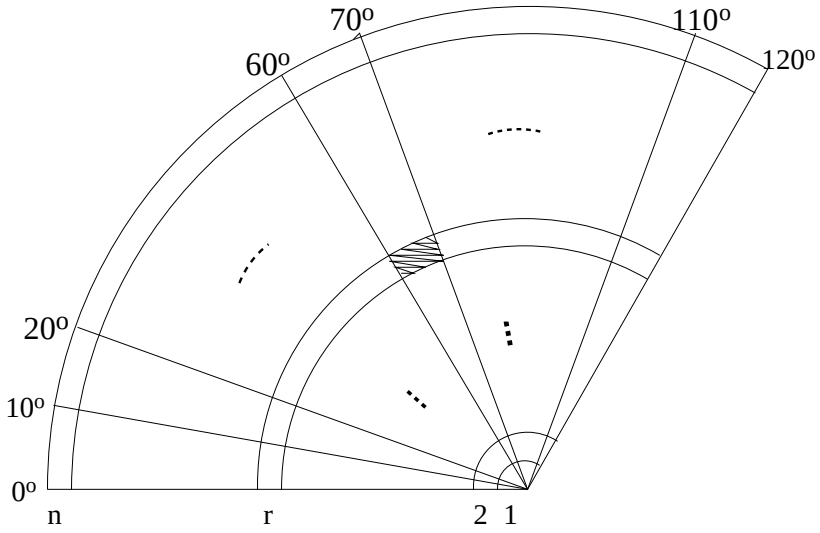

Figure 4.2: Sample of a Sector

CPT for $\mathbb{P}(A/MA)$

While measuring CQI values at known locations, angle of arrival of signal from measuring equipment can be calculated at Node B. This information is used with actual angle of the location where measuring equipment was at that time from Node B, to calculate the probabilities of possible directions of UE in terms of angle for given measured angle and this probability distribution is shown in $\mathbb{P}(A/MA)$. These probability distribution mainly depend on accuracy of the angle measurement mechanism at Node B. As shown in figure 4.2, here a range of degree is taken as a single direction, for example, $0^o - 10^o$ is treated as single direction.

CPT for $\mathbb{P}(L/A)$

As shown in figure 4.2, whole sector can be divided in to small areas by taking range of distance from Node B and range of angle. These small areas are called location and $\mathbb{P}(L/A)$ gives probability distribution of UEs in these locations for given direction A. One such sample location is shown in figure 4.2 and is identified by distance 'r' and angle $60^o - 70^o$.

CPT for $\mathbb{P}(CQI/L)$

As samples of CQI values and locations from where the samples where taken is known, it is possible to estimate $\mathbb{P}(CQI/L)$ by simply calculating probability of CQI at every possible location.

4.4.4 Inferring Location

Now, $\mathbb{P}(A/MA)$, $\mathbb{P}(L/A)$ and $\mathbb{P}(CQI/L)$ are known at Node B. At every TTI CQI value is sent by UE to Node B. These CQI values should be averaged over some TTIs so that effect of multipath is reduced. Angle of arrived signal can be measured at Node B. These information, averaged CQI value (cqi) and measured angle (ma), can be used as evidence and $\mathbb{P}(L/cqi, ma)$ is calculated as shown below:

$$\mathbb{P}(L/cqi, ma) = \alpha\mathbb{P}(L, cqi, ma)$$

Now, summing out over remaining variable, A

$$\mathbb{P}(L/cqi, ma) = \alpha \sum_{a} \mathbb{P}(L, cqi, ma, a)$$

For this BN above formula can be written as,

$$= \alpha \sum_{a} \mathbb{P}(cqi/L)\mathbb{P}(L/a)P(a/ma)P(ma)$$

As, $P(ma)$ is constant it can be added in normalization factor.

$$\mathbb{P}(L/cqi, ma) = \alpha \sum_{a} \mathbb{P}(cqi/L)\mathbb{P}(L/a)P(a/ma) \tag{4.1}$$

Now, all three factors within summation,$\mathbb{P}(cqi/L)$, $\mathbb{P}(L/a)$, $P(a/ma)$ can be computed using available CPTs.

This equation 4.1 gives probabilities of all possible location where the UE should be given the $CQI = cqi$ and $MA = ma$.

4.5 Construction of Markov Chain

As location estimation should be done after every few milliseconds the UE can move only few meters in these small time. So, it is perfectly right to say that current location of the UE depends on the previous location, i.e. current location should be within some range of previous location. This can be modeled using **Markov chain** or **Markov process**[10] as shown in figure 4.3. Here each location is called a state. This is first order Markov chain in which the current state depends only on previous state.

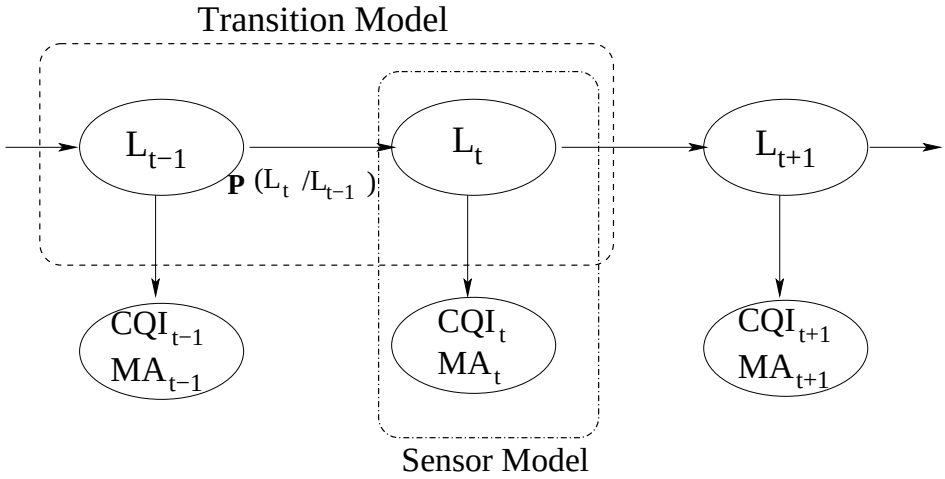

Figure 4.3: Markov Chain

As shown in figure 4.3, Markov chain can divided in to two models, transition model and sensor model. The laws describing how the state evolves over time are contained entirely within conditional distribution $\mathbb{P}(L_t/L_{t-1})$, which we call the **transition model**. The conditional distribution $\mathbb{P}(CQI_t, MA_t/L_t)$ is called **sensor model** or **observation model**.

Now, the current location can be estimated using evidences (CQI and MA) and the previous state (location) information using the filtering, i.e. computing the belief state - the posterior distribution over the current state, given all evidence to date. That is we wish to compute $\mathbb{P}(L_{t+1}/cqi_{1:t+1}, ma_{1:t+1})$.

Dividing up the evidence,

$$\mathbb{P}(L_{t+1}/cqi_{1:t+1}, ma_{1:t+1}) = \mathbb{P}\left(L_{t+1}/[cqi_{t+1}, ma_{t+1}], [cqi_{1:t}, ma_{1:t}]\right)$$

Using Bayes Rule,

$$= \alpha\mathbb{P}([cqi_{t+1}, ma_{t+1}]/L_{t+1}, [cqi_{1:t}, ma_{1:t}])\mathbb{P}(L_{t+1}/cqi_{1:t}, ma_{1:t})$$

Here evidence variables at time t depend only on current state. So,

$$= \alpha\mathbb{P}([cqi_{t+1}, ma_{t+1}]/L_{t+1})\mathbb{P}(L_{t+1}/cqi_{1:t}, ma_{1:t})$$

In this equation $\mathbb{P}([cqi_{t+1}, ma_{t+1}]/L_{t+1})$ is obtainable from sensor model. $\mathbb{P}(L_{t+1}/cqi_{1:t}, ma_{1:t})$ represents a one step prediction for next step and obtained by conditioning on L_t,

$$= \alpha\mathbb{P}([cqi_{t+1}, ma_{t+1}]/L_{t+1}) \sum_{l_t} \mathbb{P}(L_{t+1}/l_t, cqi_{1:t}, ma_{1:t})P(l_t/cqi_{1:t}, ma_{1:t})$$

Using Markov property,

$$= \alpha\mathbb{P}([cqi_{t+1}, ma_{t+1}]/L_{t+1}) \sum_{l_t} \mathbb{P}(L_{t+1}/l_t)P(l_t/cqi_{1:t}, ma_{1:t}) \tag{4.2}$$

Within the summation, the first factor $\mathbb{P}(L_{t+1}/l_t)$ is simply the transition model and the second $P(l_t/cqi_{1:t}, ma_{1:t})$ is state distribution at time t, which can be calculated recursively.

So, equation 4.2 returns probabilities of possible locations where UE should be at time $t+1$ depending on location at previous time, in addition to given evidences, CQI value 'cqi' and measured angle 'ma'.

4.6 Learning Sector-Specific Information

The conditional probability tables used in this method include the detail of distribution of UEs and geographical situations affecting channel condition in the given sector. CPTs contain relevant sector-specific information and must be learned for each sector.

In the sector, probability of user at office and other buildings, highways, etc. places is higher, whereas places like, open fields, revers, ponds, mountains have low probability of users. These details of UE's distribution over the sector can be nicely included in $\mathbb{P}(L/A)$.

Obstacles in the sector,like buildings, mountains, etc. cause shadowing effect. And as the distance between UE and Node B increases, distance losses also increase. These details are included in $\mathbb{P}(CQI/L)$ as samples collected for constructing $\mathbb{P}(CQI/L)$ were affected by these losses.

Chapter 5

Conclusion & Future Work

5.1 Conclusion

In this thesis, two methods are investigated for prediction of CQI values and one method is proposed for localization.

In chapter 3, two methods for CQI prediction are given. From the results of the experiments, conducted on the CQI traces generated in different environments, it is clear that both methods performs equally well. But the method using Least-Squares Line is simple and computationally faster then the method using Spline, and gives same results. So method using Least-Squares Line is more preferable.

Markov Chain Model is proposed in chapter 4, which uses AOA information and recent CQI values available at Node B, with sector specific information to estimate UE's location. Sector-specific information, like distribution of UEs and CQI values over the sector, must be learnt from empirically collected data for the sector. Accuracy of this method depends on, accuracy of learning of sector-specific information and AOA measurement.

Proposed Markov Chain Model can be simulated using sector-specific information for some real-world sector, with actual CQI traces and AOA information for the UE moving in that sector. Due to lack of time and unavailability of these prerequisite information, we are not able to simulate and check its functionality.

5.2 Future Work

Current scheduling algorithms can be amended to schedule UEs depending on predicted future CQI values instead of current CQI value.

Proposed Markov Chain Model can be simulated by acquiring the prerequisite data mentioned in the section 5.1 from real world or using some simulator.

Depending on the previous location estimations and sector-specific information, possible future location of UE and from that future channel quality can be predicted.

Self learning capability can also be added to the proposed Markov Chain Model, so that it will adapt the changes done in the sector, like construction of new building or road.

Appendix A

Curve Fitting

In science and engineering it is often the case that an experiment produces a set of data points $(x_1, y_1), (x_2, y_2), \ldots, (x_N, y_N)$ where the abscissas $\{x_k\}_{k=1}^N$ are distinct. One goal of numerical methods is to determine a formula $y = f(x)$ that relates these variables. Usually, a class of allowable formulas is chosen and then coefficients must be determined. There are many possibilities for the type of functions that can be used. In this chapter, two methods are explained, Least Squares Line[11] and Spline[11].

A.1 Least Squares Line

Let $\{(x_k, y_k)\}_{k=1}^N$ be a set of N points, where the abscissas $\{x_k\}_{k=1}^N$ are distinct. The **least-squares line** $y = f(x) = Ax + B$ is the line that minimizes the root-mean square error. Root mean square error can be calculated by following equation.

$$Root\ Mean\ Square\ Error\ E(f) = \left[\frac{1}{N}\sum_{k=1}^{N}|f(x_k) - y_k|^2\right]^{1/2}$$

The quantity $E(f)$ will be a minimum if the quantity $N\left[E(f)\right]^2 = \sum_{k=1}^{N}\left(Ax_k + B - y_k\right)^2$ is minimum. The later is visualized geometrically in figure A.1 by minimizing the sum of the squares of the vertical distances from the points to the line.

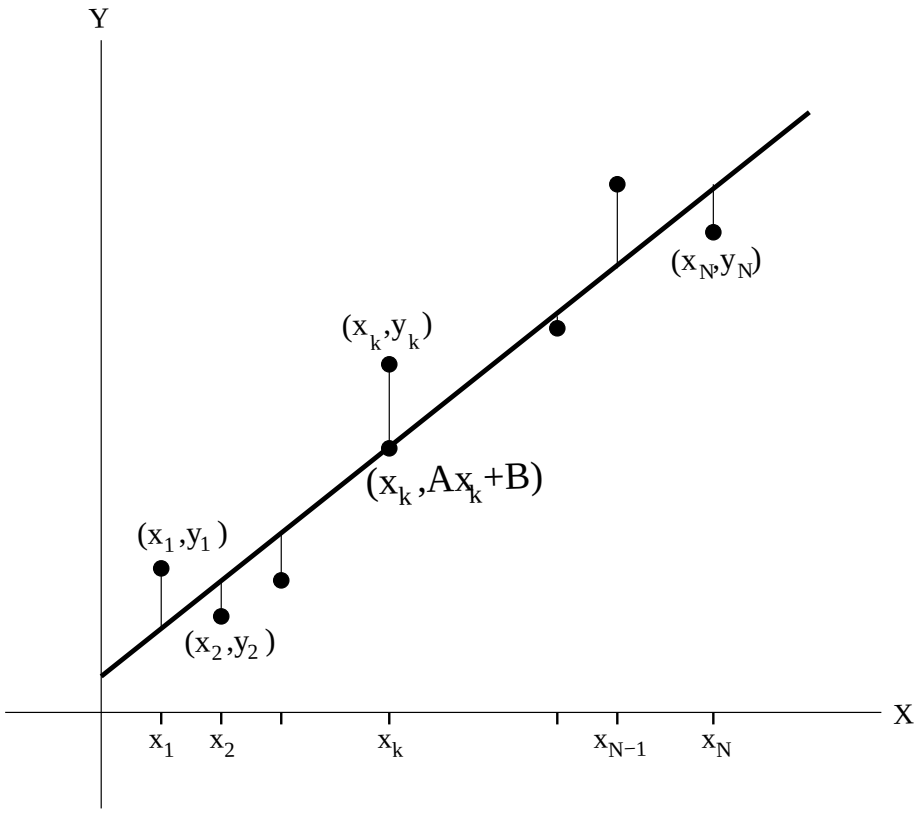

Figure A.1: The vertical distances between the points $\{(x_k, y_k)\}$ and the least-squares line $y = Ax + B$

For given N points, $\{(x_k, y_k)\}_{k=1}^N$ where abscissas $\{x_k\}_{k=1}^N$ are distinct, the coefficients of the least-squares line

$$y = Ax + B \tag{A.1}$$

are the solution to the following linear system:

$$\left(\sum_{k=1}^{N} {x_k}^2\right) A + \left(\sum_{k=1}^{N} x_k\right) B = \sum_{k=1}^{N} x_k y_k \tag{A.2}$$

$$\left(\sum_{k=1}^{N} x_k\right) A + NB = \sum_{k=1}^{N} y_k \tag{A.3}$$

In equations A.2 and A.3, $\{x_k\}_{k=1}^N, \{y_k\}_{k=1}^N$ and N are known quantities, so A and

B can be calculated easily and replaced in equation A.1 to get least-squares lines.

A.2 Spline Function

Polynomial interpolation is good for small set of points. But for a large set of $N+1$ points $\{(x_k, y_k)\}_{k=1}^{N+1}$ is frequently unsatisfactory because the degree of the approximating polynomial may have to be chosen unacceptably large. And a polynomial of degree N can have $N-1$ relative maxima and minima and the graph can wiggle in order to pass through the points. Another method is to "piece together" the graphs of lower-degree polynomials $S_k(x)$ and interpolate between between the successive nodes (x_k, y_k) and (x_{k+1}, y_{k+1}). The two adjacent portion of the curve $y = S_k(x)$ and $y = S_{k+1}(x)$, which lie above $[x_k, x_{k+1}]$ and $[x_{k+1}, y_{k+2}]$, respectively, pass through common knot (x_{k+1}, y_{k+1}). The two portions of the graph are tied together at the knot (x_{k+1}, y_{k+1}). The set of functions $\{S_k(x)\}_{k=1}^{N}$ form the piecewise polynomial curve which is denoted by $S(x)$. This can even be done in such a way that the polynomial pieces blend smoothly, i.e., so that the resulting patched or composite function $S(x)$ has several continuous derivatives. Any such smooth piecewise polynomial function is called a *spline*.

A.2.1 Piecewise Cubic Spline

When piecewise cubic polynomials are used to construct spline then its called *Cubic Spline*[11]. It is possible to construct cubic functions $\{S_k(x)\}_{k=1}^{N}$ on the interval $\{[x_k, x_{k+1}]\}_{k=1}^{N}$ so that the resulting piecewise curve $y = S(x)$ and its first and second derivatives are all continuous on the large interval $[x_1, x_{N+1}]$.

Suppose that $\{(x_k, y_k)\}_{k=1}^{N+1}$ are $N+1$ points where $a = x_1 < x_2 < \cdots < x_{N+1} = b$. The function $S(x)$ is called a **cubic spline** if there exists N cubic polynomials $S_k(x)$ with the properties:

a. $S(x) = S_k(x) = s_{k,0} + s_{k,1}(x - x_k) + s_{k,2}(x - x_k)^2 + s_{k,3}(x - x_k)^3$

for $x \in [x_k, x_{k+1}]$ for each $k = 1, 2, \ldots, N$.

b. $S(x_k) = y_k$

for $k = 1, 2, \ldots, N+1$.

The spline passes through each data point.

c. $S_{k-1}(x_k) = S_k(x_k)$

for $k = 2, 3, \ldots, N$.

The spline forms a continuous function.

d. $S'_{k-1}(x_k) = S'_k(x_k)$

for $k = 2, 3, \ldots, N$.

The spline forms a smooth function.

e. $S''_{k+1}(x_k) = S''_k(x_k)$

for $k = 2, 3, \ldots, N$.

The second derivative is continuous.

A.2.2 Construction of Cubic Spline

$$
\begin{aligned}
h_{k-1}m_{k-1} + 2\left(h_{k-1} + h_k\right)m_k + h_k m_{k+1} \quad &= \quad u_k \qquad\qquad (A.4)\\
\textit{where} \quad & h_k = x_{k+1} - x_k,\\
& m_k = S''(x_k),\\
& u_k = 6(d_k - d_{k-1}),\\
& d_k = \frac{y_{k+1} - y_k}{h_k}\\
\textit{for} \quad & k = 2, 3, \ldots, N.
\end{aligned}
$$

In the equation A.4, unknowns $\{m_k\}_{k=1}^{N+1}$ are desired values and the other terms are constants obtained by performing simple arithmetic with the data points $(x_k, y_k)_{k=1}^{N+1}$.

Therefore, in reality system A.4 is an undetermined system of $N-1$ linear equations involving $N+1$ unknowns. Hence two additional equations must be supplied. They are used to eliminate m_1 from equation 1 and m_{N+1} from equation $N-1$, in system A.4. The standard strategies for the endpoints constraints are summarized in Table I.

Description of the strategy	**Equations involving $\mathbf{m_1}$ and $\mathbf{m_{N+1}}$**
"'Clamped cubic spline"': specify $S^{'}(x_1), S^{'}(x_{N+1})$.	$m_1 = \frac{3}{h_0}\left[d_1 - S^{'}(x_1)\right] - \frac{m_2}{2}$, $m_{N+1} = \frac{3}{h_N}[S^{'}(x_{N+1}) - d_N] - \frac{m_N}{2}$
"'Natural cubic spline"'(a "'relaxed curve"').	$m_1 = 0, m_{N+1} = 0$
Extrapolate $S^{''}(x)$ to the end points.	$m_1 = m_2 - \frac{h_1(m_3 - m_2)}{h_2}$, $m_{N+1} = m_N + \frac{h_N(m_N - M_{N-1})}{h_{N-1}}$
$S^{''}(x)$ is constant near the end points.	$m_1 = m_2, m_{N+1} = m_N$
Specify $S^{''}(x)$ at each end point.	$m_1 = S^{''}(x_1), m_{N+1} = S^{''}(x_{N+1})$

Table I: End Point Constraints for a Cubic Spline

Now, using the $N-1$ equations given by system A.4 and two by using one of the constraints given in table I, it is possible to solve the system and evaluate the spline function.

Appendix B

Tool Used

B.1 EURANE

EURANE (Enhanced UMTS Radio Access Network Extensions for ns-2)[12] is a patch used in network simulator 2.0 (ns-2) for simulations on Universal Mobile Telecommunications Services (UMTS) networks. EURANE adds functionality to ns-2 to support HSDPA. EURANE has two modules as shown in figure B.1.

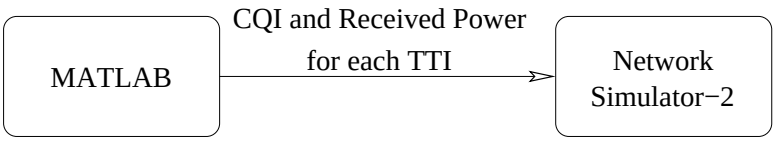

Figure B.1: EURANE Architecture

First module which is implemented in MATLAB, is used to simulate physical channel and part of physical layer of the HSDPA. This module takes, environment in which UE is situated, distance between UE and BS, speed of UE, time duration for simulation and number of UEs, as an input and gives one file for each UE, which contains CQI values, and received power at BS for each TTI for whole simulation run.

Second module takes the files generated by first module as input and use them for simulation of HSDPA architecture.

Appendix C

Abbrevations

3GPP	3rd Generation Partnership Project
AOA	Angle of Arrival
AMC	Adaptive Modulation And Coding
CQI	Channel Quality Indicator
EURANE	Enhanced UMTS Radio Access Network Extensions for ns-2
HARQ	Hybrid Automatic Repeat Request
HSDPA	High-Speed Downlink Packet Access
HS-DPCCH	High-Speed Dedicated Physical Control Channel
HS-DSCH	High-Speed Downlink Shared Channel
HS-SCCH	High-Speed Shared Control Channel
LOS	Line-of-Sight
MAC	Medium Access Control
MAC-hs	Medium Access Control high-speed
QoS	Quality of Service
RLC	Radio Link Control
RNC	Radio Network Controller
SNR	Signal-to-Noise Ratio
TDOA	Time Difference of Arrival
TOA	Time of Arrival
TTI	Transmission Time Interval
UE	User Equipment
UMTS	Universal Mobile Telecommunications Services

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