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Agenda Item: AH24: High Speed Downlink Packet Access
Source: **Wiscom Technologies**
Title: Long-Range Prediction (LRP) of Faded Signals in HSDPA for FDD and TDD
Document for: Discussion and Approval for Text Proposal

1 Introduction

Following previous work [7,10], we continue to propose the Long Range Prediction (LRP) based channel prediction in HSDPA for both FDD and TDD mode. Link level and system level simulations show that LRP can improve system performance of FDD HSDPA in several ways. For example, we use channel prediction to only compensate **for the MCS feedback delay**. At speed of 15 kmph, the improvement in the throughput achieved by using LRP based channel prediction may be 1.0-1.5 dB for Ec/Ioc between -5 to 5dB. This significant gain justifies the use of LRP channel prediction in HSDPA. The full potential of the LRP may be even more promising by using the LRP channel prediction in areas such as Predictive/Adaptive transmitter diversity, ARQ, Scheduling, Cell Site Selection, Multi-code and MIMO Antenna Processing.

The simulation results regarding the effect of channel estimation error on the link level and system level performance of HSDPA show [1,2,4,5,6] that the link level and system level performance is very sensitive to the channel estimation (to obtain channel phase and amplitude). From link level point of view, accurate channel estimation is essential, especially in the situation of higher modulation, Turbo code and high vehicle speed. From system level point of view, channel quality estimation and prediction are essential. For eample, availability of channel conditions in the future sub-frames makes radio resource scheduling more flexible and effective.

The need of LRP based channel prediction has fundamental impact on limitation of HSDPA in terms of peak data rate and vehicle speed. If we use the LRP for system level applications, some signaling is involved. For example, what information shall be reported back from UE to Node B ? In this sense LRP based channel prediction involves more than implementation issues. That is the reason why we propose LRP in AH24.

The idea of a communication system where the transmitter has the side information feedback from receiver to transmitter was traced back at least to Claude E. Shannon as early as in the 1950s. Channels with feedback from the receiving to the transmitting point are special case of a situation in which there is additional information available at the transmitter which may be used as an aid in the forward transmission system. Along with this line, a lot of ideas such as adaptive transmission techniques appeared to solve the problems in the fading channel.

2 Performance Bounds

For the QAM we can get upper and lower performance bounds. For square-QAM, carrier regeneration using pilot-aided signal is essential. When we apply Gray encoding with absolute phase coherent detection. the lower bound of BER for Gray-encoded 16QAM and 64QAM is in AWGN given by

$$
\begin{aligned}
P_{e16QAM} &\approx \tfrac{3}{8}\,erfc\left(\sqrt{\tfrac{2}{5}\gamma_b}\right) - \tfrac{9}{64}\,erfc^2\left(\sqrt{\tfrac{2}{5}\gamma_b}\right) \\
P_{e64QAM} &\approx \tfrac{7}{24}\,erfc\left(\sqrt{\tfrac{1}{7}\gamma_b}\right) - \tfrac{49}{384}\,erfc^2\left(\sqrt{\tfrac{1}{7}\gamma_b}\right)
\end{aligned}
\quad (1)
$$

For Rayleigh fading channel, we have the upper bound

$$
\begin{aligned}
P_{e16QAM} &\approx \tfrac{3}{8}\left[1 - \frac{1}{\sqrt{1 + \frac{5}{2\gamma_b}}}\right] \\
P_{e64QAM} &\approx \tfrac{7}{24}\left[1 - \frac{1}{\sqrt{1 + \frac{7}{\gamma_b}}}\right]
\end{aligned}
\quad (2)
$$

From (1) and (2), clearly we should try our best to approach the lower bound (1) (for the perfect channel estimation and fading compensation) with the aid of the channel estimation. This bound motivates the study of this contribution using a novel technique called Long Range Prediction (LRP). The scope of this study in channel estimation and prediction includes not only link level issues like the modulation and coding but also the system issues like ARQ and antenna diversity.

From system level point of view, LRP based channel prediction can compensate for the delay of the system processing and propagation delay such as MCS measurement and selection delay. This mechanism can improve the system performance.

3 Principle of Long-Range Prediction (LRP)

In WCDMA, several adaptive transmission techniques, including adaptive modulation and coding, power/rate control, antenna diversity, ARQ, and others, are used for adaptation to rapidly time variant fading channel conditions. Since the channel changes rapidly, the transmitter and receiver are usually not designed optimally for current channel conditions and thus fail to take advantage of the full potential of the wireless channel. By exploiting the time-varying nature of the wireless multipath fading channel, all these adaptive schemes are trying to use power and spectrum more efficiently to realize higher bit-rate transmission without sacrificing the bit error rate (BER) performance. To implement the adaptive transmission methods, the channel state information (CSI) often may be available at the transmitter. CSI can be estimated at the receiver and sent to the transmitter via a feedback channel. Feedback delay, overhead, processing delay and etc are considered. For very slowly fading channels (pedestrian or low vehicle speed for most HSDPA applications), outdated CSI is sufficient for reliable adaptive system design. For faster vehicle speed, we need LRP in order to realize the potential of adaptive transmission methods. These channel variations have to be reliably predicted at least several milliseconds (ms), or tens to hundreds of data symbols. Notice that one frame (15 slots) of WCDMA is 10 ms. The goal of LRP is to enable the adaptive transmission techniques.

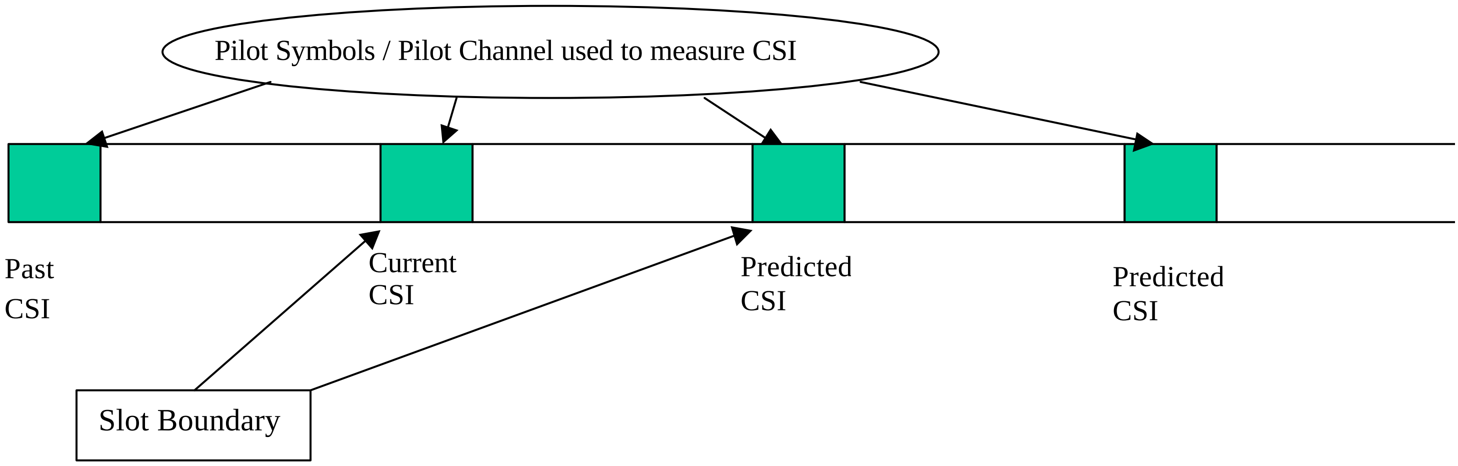

Fig. 1 The Channel State Information (CSI) is obtained using either time-multiplexed pilot symbols (transmitted in DPCCH) or code-multiplex pilot channel signals (transmitted in CPICH).

4 Use of LRP for HSDPA

Many studies have addressed estimation of current fading conditions, prediction of future fading conditions through LRP has not been addressed until recently. In this contribution, following [7,10] we continue to use this new tool to improve the performance of WCDMA, especially for HSDPA applications. As shown in Fig. 2 and Fig. 3 we proposed a novel WCDMA system paradigm that uses the mechanisms of prediction of future fading conditions. The spirit and principle of this system paradigm can be used for other system design such as CDMA2000, TDD. Our major contribution is to study how the proposed new system paradigm through LRP will improve the WCDMA system performance, especially high speed packet access, including

1. Predictive/Adaptive modulation
2. Predictive/Adaptive channel coding/Turbo coding
3. Predictive/Adaptive transmitter diversity
4. Predictive/Adaptive ARQ
5. Predictive/Adaptive Scheduling
6. Predictive/Adaptive Cell Site Selection
7. Predictive/Adaptive Multi-Code
8. Predictive/Adaptive Multiple Input and Multiple Output (MIMO) Antenna Processing.

An intuitive justification of use of LRP for HSDPA is the sensitivity of the above techniques to the fading CSI. We know from a lot of other studies in different branches that "knowing" or predicting the fading CSI reduces the error of channel estimation, thus improving the performance of the system in both link level and system level. The link level performance has been confirmed in [1,2,4,5] where the channel estimation error of 2% relative to the channel power seems to block the link level performance of HSDPA for high vehicle speed (e.g. 30 kmh). We also observed [5] for fixed feedback MCS selection delay, the channel measurement accuracy can lead to 2 dB performance loss. This suggests more advanced MCS selection rule to improve AMCS and HARQ performance. The reason for the above results is that high-level QAM and Turbo code are very sensitive fading CSI. Turbo code can be used for transmitting high-speed CDMA data since the CDMA channel is closer to the complex Gaussian noise in the multipath fading channel.

On the other hand, higher modulation has a potential to achieve a high bit rate and a high spectral efficient system, BUT it depends on the anti-fading compensation techniques, non-linear compensation techniques, and the service demand. Another difficulty of channel estimation for QAM is the need for amplitude variation. In the M-ary QAM, a symbol is generated according to $\log_2 M$-bit of the source data. Because coherent detection is essential for square-QAM (that has been proposed in HSDPA [4]), carrier regeneration using pilot signal-assisted schemes (CDM in CPICH or TDM DPCCH)) is necessary for M-ary QAM. It is well known that QAM is sensitive to fading CSI. Thus any improvement in fading CSI will convert into gains in techniques such as Turbo code and QAM.

A critical fact is that the transmission efficiency under flat Rayleigh fading conditions with smaller maximum Doppler frequency f_d is higher than that AWGN channel conditions because long error-free length is more probable under fald Rayleigh fading conditions with smaller f_d than under AWGN channel conditions due to burstness of the error sequence. This is one of reasons to justify ARQ or Hybrid ARQ in HSDPA. This fact also implies that "knowing" f_d in advance of one future frame or future 10-15 slots/sub-frames, say, by means of LRP, seems to increase the transmission efficiency of a system with ARQ under flat Rayleigh fading channel conditions [6]. In [6] we confirmed that the MCS selection delay is likely to cause about 1 dB performance loss. In addition when f_d increases, transmission efficiency decreases because error-free length becomes short with increasing f_d. Obviously we find transmission efficiency depends on bit energy E_b/N_0.

Scheduling of resources benefits from the knowing the future fading CSI and tries to avoid the transmission when channel is not in good conditions. The proposed technique will help reduce the scheduling delay and improve the throughput. This is confirmed by simulations in [9] where MCS delay is compensated by using LRP.

Although space diversity is a very effective technique for compensating for rapid fading, it is helpless to compensate for log-normal fading or path loss due to distance. This requires so-called site diversity to obtain independent diversity paths by using plural base stations. In the case of Fast Cell selection, the UE selects the best cell every frame from which it wants to receive data on the HS-DSCH. HS-DSCH data is then transmitted to the UE from this cell only. UE can better select the best frame once UE knows the future fading CSI.

If we know the fading CSI, we can adaptively adjust the use of multi-code. MIMO Multiple antennas seem to be sensitive to the fading CSI. The improved performance of LRP used for the fading CSI will definitely help MIMO antenna processing.

5 FDD Simulation Results without Channel Prediction

To support the claims in the Sections 3 and 4, we performed a lot of simulations using our simulation platform that was calibrated against others [1,2]. So far we investigated the benefit of using LRP by studying both the link level and system level performance.

In the work [1,2], we presented the link simulations that were collected into the HSDPA Technical Report [4]. The results show that the link level performance of higher order modulation is very sensitive to the channel estimation (used for channel compensation and other purposes) and thus accurate channel estimation is essential, especially at high vehicle speeds. In [5] we presented the simulation results of AMCS and HARQ for HSDPA in the non-ideal measurement and feedback situations assuming the fixed MCS selection delay. For the typical value of Ec/Ioc, the channel measurement accuracy has large impact on the throughput, i.e. up to 2 dB loss compared with the ideal case measurement and feedback defined in [5]. It suggests that at slow vehicle speed, longer time CPICH average might be necessary for more accurate measurement to improve the throughput. However, at fast vehicle speed, the long time average might fail to track the channel condition closely. Thus, more advanced MCS selection rule might include both long term and short term channel average as well as Doppler frequency estimation to improve the AMCS and HARQ performance. Further investigation is needed in this topic. These above results verified the values of the proposed approach such as Predictive/Adaptive modulation and Predictive/Adaptive channel coding/Turbo coding.

To illustrate the value of the proposed approach for system level performance, we investigated the effect of MCS selection delay on the performance of AMCS and HARQ for HSDPA [6]. The performance loss due to the MCS delay is not significant at very slow vehicle speed. However it increases at higher vehicle speeds and larger MCS selection delays. For typical operating points, the loss due to the MCS delay can be as large as 1 dB or 22% throughput loss. Thus the technique to predict the channel condition might help to reduce such performance loss. The channel prediction technique can be incorporated with the MCS selection rule to improve the AMCS and HARQ performance in HSDPA.

6 FDD Simulation Results with Channel Prediction

We used channel prediction for faded signals based on Jakes and spectrum filter models. Using our algorithms, channel prediction works very well up to 1 wavelength and fairly good up to 2 wavelengths. In particular, for the Doppler frequency f_d=30Hz case, it means 3-6 radio frames (or 9-18 high speed data frames). The results are shown in Fig. 4 and Fig. 5. These results are for very high SNR. For other SNR cases, the results will have some degradation, as expected. But the principle works fairly well.

Wiscom Technologies also has performed comparisons regarding the cases with or without channel prediction. LRP based channel prediction is implemented using the simulation platform we used before [9, 1-7]. Detailed results are beyond the scope of this paper. Details of simulations are described in [9]. Rather we show a typical case in Fig. 6. In Fig. 6 channel prediction is used to compensate for the MCS feedback delay only. It is shown that channel prediction can improve system performance greatly. As a typical example, at speed of 15kmph, the improvement in the throughput achieved by using channel prediction is 1.0-1.5 dB with Ec/Ioc between -5 to 5dB. This significant gain can justify the use of LRP channel prediction in HSDPA, as proposed in the previous papers [7, 10]. The full potential of the LRP is expected to be much promising by using the LRP channel prediction for other areas such as Items 3-8 of Section 4.

7 Channel Prediction for TDD HSDPA

Chapter 8 of TR 25.848 [4] [13] proposes to support HSDPA for TDD mode. The principles of the described technologies are applicable for both FDD and TDD. However the methods and details have only been considered for FDD. Section 8 [4] presents the applicability of the proposed techniques for the TDD mode. TDD mode specific differences compared to FDD are highlighted.

LRP based channel prediction has proven to work for FDD mode. For details see sections 12.4.3, 12.4.4, and 7.1.2.1.1.6 of TR 25.848 V. 0.5.0 [4] and our paper [11]. In this paper we further propose to apply this approach to TDD mode [12], as suggested in section 4 of the paper presented in the last meeting by Wiscom Technologies [7].

The TDD Mode is a time slot based transmission system with a time slot granularity of 666µs. Each 10 ms frame consists of some time slots, each allocated to either the uplink or the downlink (Figure 7). In any configuration at least one time slot has to be allocated for the downlink and at least one time slot has to be allocated for the uplink.

The fact that uplink and downlink use the identical RF channel makes fundamental sense to use LRP based channel prediction in the TDD HSDPA. In practice the LRP based channel prediction can accurately predict the channel conditions up to a radio frame. Thus uplink and downlink can share the information of channel conditions. In fact compared with FDD the complexity of implementing LRP in TDD is much lower since there is no feedback needed to transmit information about channel conditions from UE to Node B. Therefore it is more natural to use LRP based channel prediction for TDD HSDPA.

We are investigating the use of the LRP approach through simulations. To accomplish that, we have performed link level simulation of TDD HSDPA in AWGN [14].

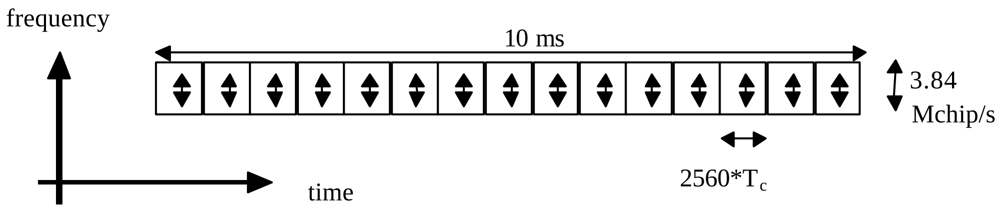

Figure 7: The TDD frame structure [12]

8 Conclusion

Following previous work, we continue to propose the Long Range Prediction (LRP) based channel prediction in HSDPA for both FDD and TDD mode. Link level and system level simulations of FDD show that LRP can improve system performance of FDD HSDPA in several ways. For example, we use channel prediction to only compensate **for the MCS feedback delay**. At speed of 15 kmph, the improvement in the throughput achieved by using LRP based channel prediction may be 1.0-1.5 dB for E_c/I_{oc} between -5 to 5dB. This significant gain justifies the use of LRP channel prediction in HSDPA. The full potential of the LRP may be even more promising by using the LRP channel prediction in areas such as Predictive/Adaptive transmitter diversity, ARQ, Scheduling, Cell Site Selection, Multi-code and MIMO Antenna Processing.

8 Text Proposal for TR 25.848

7.1.2 Complexity Evaluation <UE and RNS impacts>

7.1.2.1.1. Complexity Impacts to UE

7.1.2.1.1.1. Introduction

7.1.2.1.1.2 Detection of MCS applied by Node-B

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7.1.2.1.1.5 Measurement/Reporting of downlink channel quality

7.1.2.1.1.6 Advanced Technologies

7.1.2.1.1.6.1 Interference Cancellers and Equalizers for Higher Modulation

7.1.2.1.1.6.2 LRP Based Channel Prediction for MCS Delay Reduction

"The basic principle of LRP based channel prediction is illustrated in Fig. 1 and Fig.2. Link level and system level simulations show that LRP can improve system performance of FDD and TDD HSDPA in several ways. For example, we use channel prediction to only compensate **for the MCS feedback delay**. At speed of 15 kmph, the improvement in the throughput achieved by using LRP based channel prediction may be 1.0-1.5 dB for Ec/Ioc between -5 to 5dB. This significant gain justifies the use of LRP channel prediction in HSDPA. The full potential of the LRP may be even more promising by using the LRP channel prediction in areas such as Predictive/Adaptive transmitter diversity, ARQ, Scheduling, Cell Site Selection, Multi-code and MIMO Antenna Processing."

7.1.2.1.1.7 Conclusions

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[1] Wiscom Technologies, "Influence of channel estimation on the link level performanc of HSDPA," TSGR1#17(00) 1327, TSG-RAN Working Group 1 Meeting #17, Stocholm, Sweden, November 21-24, 2000.

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[14] Wiscom Technologies, " Link Level Simulation Results of HSDPA in TDD Mode," TSGR1#19(01) 0251, TSG-RAN Working Group 1 Meeting #19, Las Vegas, NV, USA, Feb. 27-March 2, 2001.

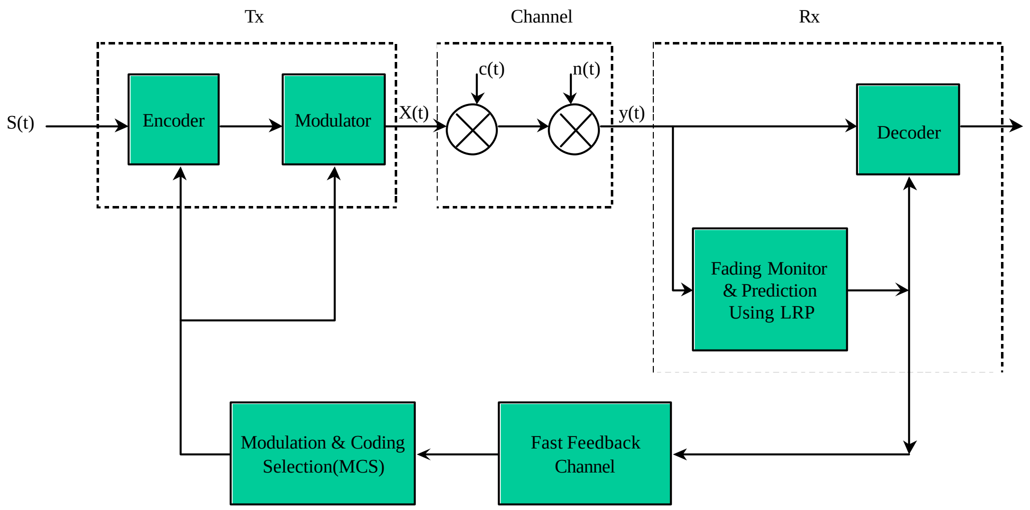


Fig.2 Illustration of Principle of Long-Range Prediction and its Application

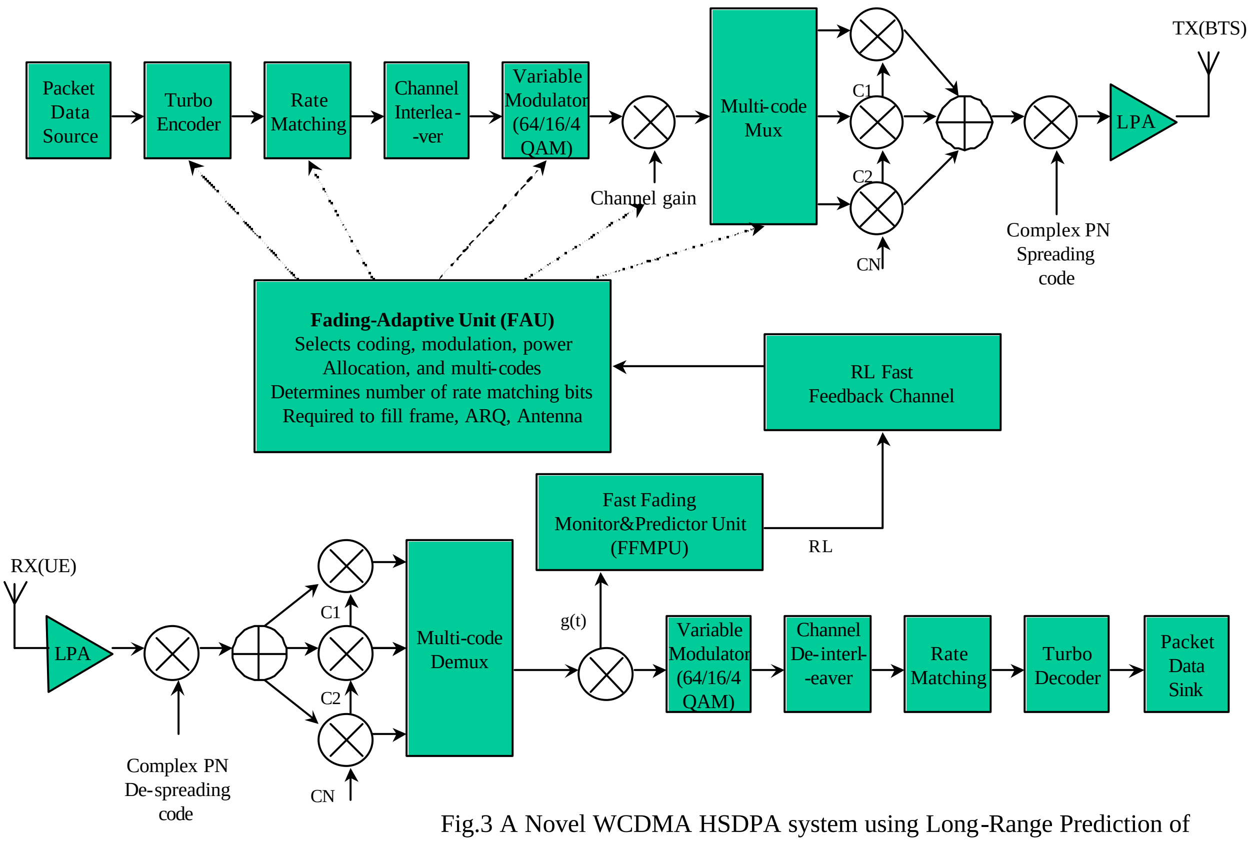
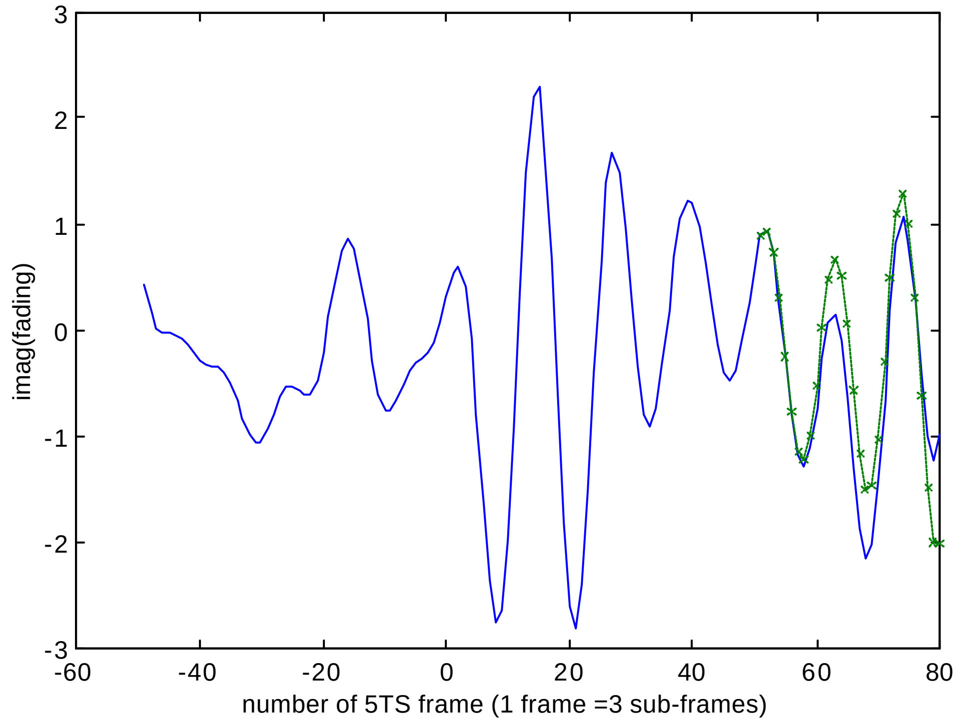


Fig.3 A Novel WCDMA HSDPA system using Long-Range Prediction of Fast Flat Fading



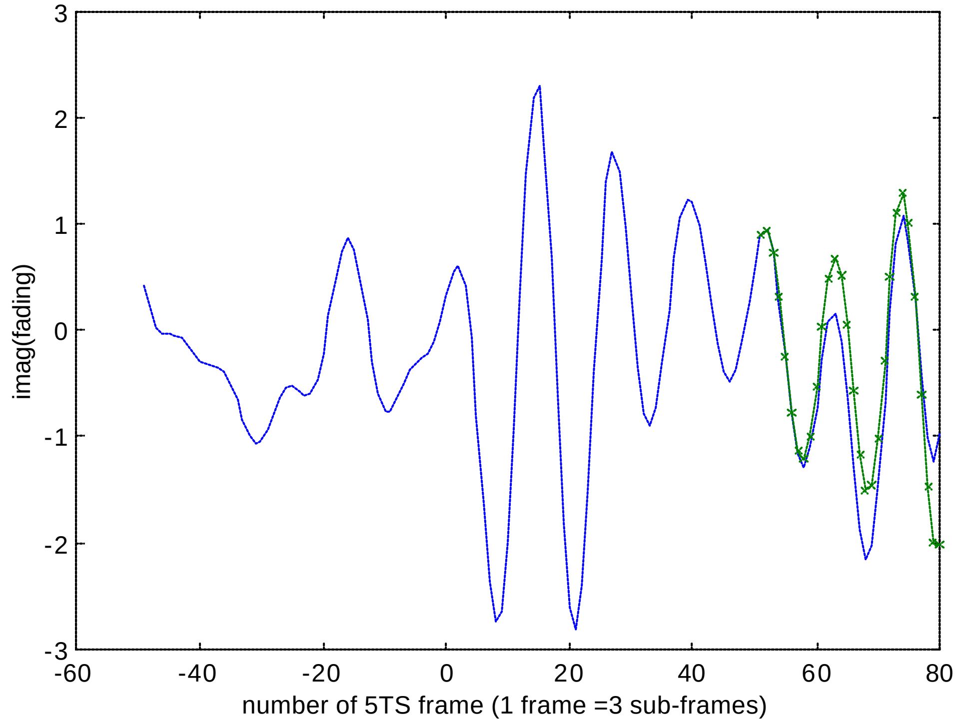


Fig. 4 Channel prediction of the real part and imaginary part of the faded signals under high signal to noise ratio.

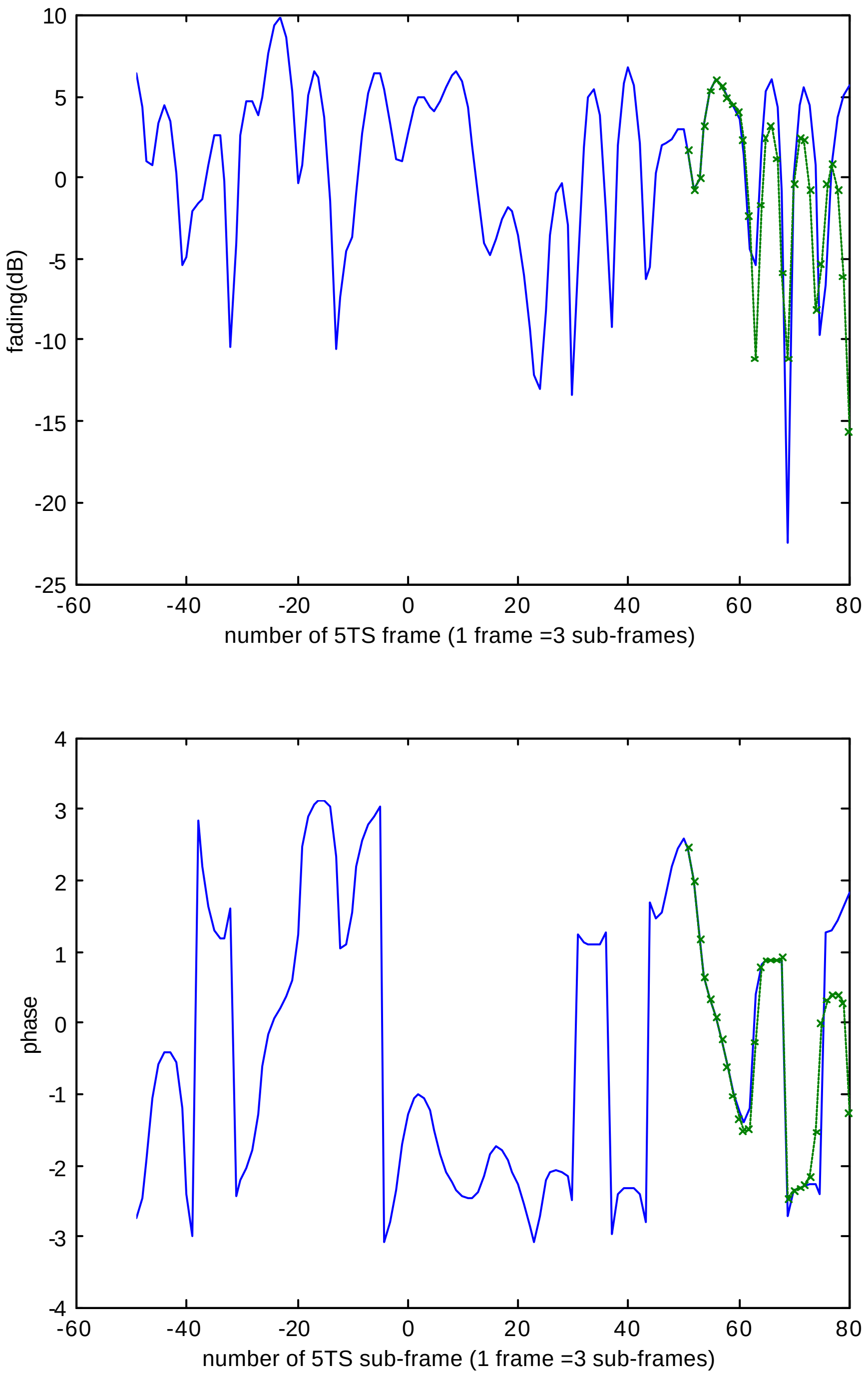


Fig. 5 Channel prediction of the power and phase of the faded signals under high signal to noise ratio.

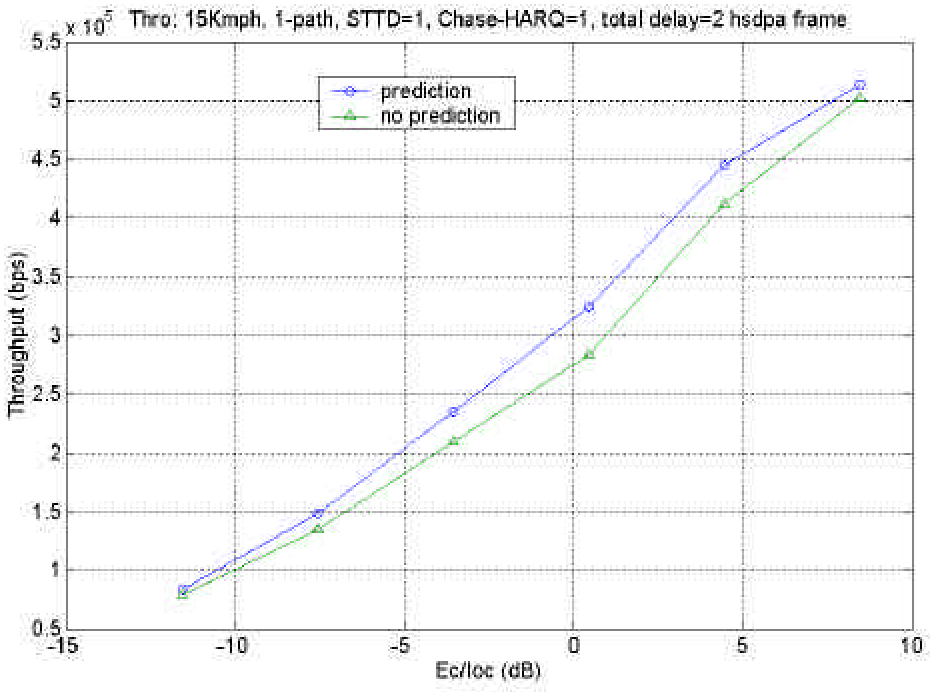


Fig. 6 Channel prediction is used to compensate for the MCS feedback delay only. Details of simulations are described in [9]. Channel prediction can improve system performance greatly. As a typical example, at speed of 15kmph, the improvement in the throughput by using channel prediction is 1.0-1.5 dB with Ec/Ioc between -5 to 5dB.