A New Technique for Capacity Enhancement in WCDMA Uplink with Synchronization

Mridula S. Korde
Visvesaraya National Institute of Technology, Nagpur, India
Department of Electronics Engineering,Shri Ramdeobaba College of Engineering & Management, Nagpur, India
Email: mridula_korde@yahoo.com;

Abhay S. Gandhi
Department of Electronics Engineering, Visvesaraya National Institute of Technology, Nagpur, India
Email: asgandhi@ece.vnit.ac.in

***Abstract*— Cellular phones have experienced an exponential growth worldwide over the last decade with more than one billion cell phone users projected in the near future. On the other hand, service providers must support new technology and infrastructure in order to fulfill their customers' requirements. These requirements include the capacity of network. The large expectances created for Wide Band Code Division Multiple Access (WCDMA) are based on its flexibility for multimedia capabilities and the high capacity it will provide. However, the demanded traffic grows rapidly, and new capacity enhancements are required in order to satisfy the future needs. Uplink synchronization can be a method to reduce the multiple access interference (MAI) by exploiting the uplink orthogonality and thereby increase the capacity of WCDMA systems. In this paper, the performance of uplink synchronous WCDMA has been assessed in terms of the capacity gain relative to an equivalent asynchronous system. The capacity gain has been evaluated theoretically and by means of MATLAB simulations for scenarios with different orthogonality factors. Orthogonality of codes is directly dependent on synchronization which in turn increases the capacity gain. In this study, it is proposed that synchronization plays an important role in enhancing the capacity gain of uplink WCDMA system. Also, an alternative solution is proposed to increase the capacity in the uplink of a synchronized WCDMA system by introducing variable modulation.**

***Index Terms*—WCDMA, WCDMA uplink, capacity gain, channelization codes**

I. INTRODUCTION

Recently, the telecommunication industries have witnessed a phenomenal growth in the development and deployment of wireless services. One major fundamental issue to address is the provision of higher capacity cellular systems with guaranteed Quality of Service (QoS) to meet its daily service demands for both enterprise and residential subscribers. Higher system capacity, better QoS and flexible accommodation of diverse wideband services such as video and multimedia services with different transmission rates are required in third generation (3G) wireless communication systems. Contrary to Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA) systems, the main limiting factor for capacity expansion in WCDMA system is the interference.

Maintaining the synchronization at the Node B in the uplink of WCDMA is not straightforward, since the transmission is started from different user equipments (UE). In 3GPP, uplink synchronized WCDMA is denoted as Uplink Synchronous Transmission Scheme (USTS). The deployment of USTS requires changes in the specifications to allow the uplink synchronism, but also to define a new code allocation rule [1].

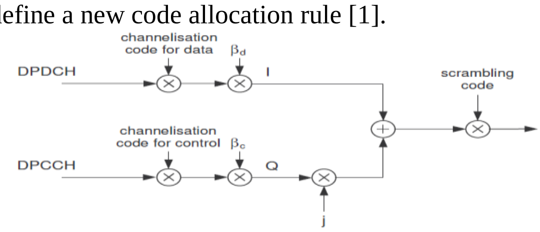

Figure 1. Spreading and scrambling of signals associated with uplink physical channels.

In a conventional uplink asynchronous WCDMA system, like the one specified in the 3GPP/Release 99, a unique pseudo random sequence is allocated to every UE. Adopting the Universal Mobile Telecommunication systems (UMTS) terminology, this pseudo random sequence is referred as scrambling codes. The signals from different physical channels associated with the same UE arrive synchronously at the BS, and can be separated by using different orthogonal channelization codes, derived from the set of Walsh codes. Hence, the narrow-band signal from a UE associated with a physical channel is both multiplied by a channelization code and a scrambling code, as depicted in the block diagram of Fig. 1. An example of scrambling and channelization code allocation for the uplink of WCDMA according to 3GPP/Release 99 is shown in Fig. 2. In uplink synchronized WCDMA, UEs within the same cell share the same scrambling code, while using different orthogonal channelization codes, as illustrated in Fig. 3. The channelization codes are utilized to separate physical

Manuscript received July12, 2013; revised September 9, 2013.

doi: 10.12720/lnit.2.1.98-104

channels from different UEs. The scrambling code is therefore cell specific.

The number of available channelization codes establishes an upper limit on the maximum number of UEs per cell in uplink synchronous WCDMA. Unlike the downlink case, the Dedicated Physical Data Channel (DPDCH) and its associated Dedicated Physical Control Channel (DPCCH) are not time-multiplexed in the uplink and use different channelization codes.

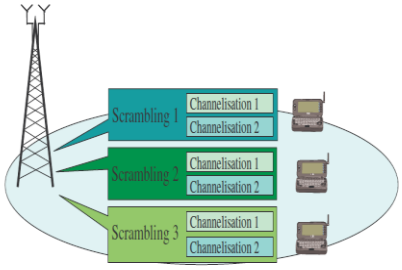

Figure 2. UE scrambling and channelization code allocation according to 3GPP/Release 99.

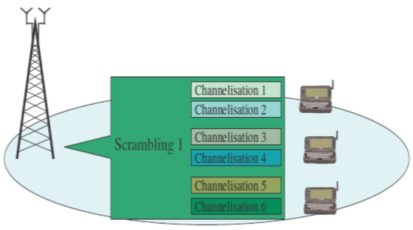

Figure 3. UE scrambling and channelization code allocation for USTS.

This restriction makes the UE use a higher number of channelization codes in general than in the downlink. However, this limitation can be lifted by introducing several scrambling code groups within a cell. This implies that a certain set of UEs is transmitted under one scrambling code while another set of UEs is transmitted under different scrambling codes. Introduction of multiple scrambling codes within a cell eliminates the constraint on the maximum number of UEs due to channelization code shortage. However, this is obtained at the expense of an increased MAI, since signals transmitted under different scrambling codes are non-orthogonal. The limited number of channelization codes under a single scrambling code is a major limitation for the capacity gain provided by uplink synchronization in UMTS [2].

In principle, the application of synchronized WCDMA in flat fading radio channels completely cancels the own-cell interference experienced at the BS (i.e., after despreading). Other-cell interference is suppressed by the basic processing gain, since UEs are assumed to be synchronized only to their serving cell. Thus, the potential capacity gain of synchronous WCDMA strongly depends on the other-to-own-cell interference ratio. Naturally, the capacity gain also depends on the degree of synchronization.

Previous studies have demonstrated that it is possible to achieve accurate symbol synchronization in the uplink by using a maximum likelihood acquisition algorithm or a simple delay-tracking loop for low mobility UEs.

A potential capacity enhancing technique is to synchronize the uplink, so that the signals transmitted from different UEs within the same cell are time-aligned at the base station (BS). This admits the utilization of orthogonal codes for own cell UE separation, so the own cell interference is in principle completely mitigated [3].

This paper is organized in following manner. Section II describes performance of uplink WCDMA under synchronous conditions. Section III describes how synchronization can be effectively used to enhance the capacity in WCDMA uplink. A new method with variable modulation is proposed and results are presented with and without the new method with synchronization. Finally, in Section IV conclusion is presented.

II. Performance of Uplink Synchronous WCDMA

WCDMA capacity is one of the key attributes in UMTS network. There are definitions of WCDMA capacity but the most of them are referred on maximum number of users per cell or of the whole observed system. The WCDMA capacity can be defined as the maximum number of simultaneous users for all services which satisfy certain conditions [4].

Here the capacity gains of uplink synchronized WCDMA in a multicell environment is quantified, assuming that user equipments (UE) can only be synchronized to one cell. The orthogonal codes used for own cell separations of UEs are assumed to be Walsh codes. This implies a finite set of orthogonal codes, which tends to limit the capacity gain of uplink synchronous WCDMA severely.

A. *Theoretical Analysis of the Noise Ratio of Uplink Synchronous WCDMA*

Here expression for the expected uplink capacity gain of a synchronous WCDMA system is derived, where it is assumed that all the UEs have the same bit rate. The maximum cell capacity is defined as a function of the number of UEs that can be supported at a given noise rise (NR) at the BS. The NR at the BS is known to be a robust measure of the uplink load of a WCDMA system, which is often used by radio resource management (RRM) algorithms to control the uplink load [5]. The NR is defined as

$$NR = \frac{Ptotal}{Pnoise} \tag{1}$$

where P_{total} is the total average received wideband power at the BS, and P_{noise} is the power of the background noise at the BS. The NR is related to the uplink load factor as

$$\eta = \frac{NR - 1}{NR} \tag{2}$$

where η ε [0, 1] is the uplink load factor. In deriving an expression for the NR, it is assumed that there are N_{async} UEs in the cell of interest which are transmitting asynchronously. In addition, there are $N_j$sync UEs in synchronous mode transmitting under scrambling code number j. Let us further more assume that the required Eb/No is identical for all the UEs.

Under these assumptions, we can approximate the Eb/No for the UEs operating in asynchronous mode as

$$\rho = G\frac{Pasnyc}{Ptotal} \tag{3}$$

where G is the effective processing gain (ratio between the chip rate and the user bit rate), and P_{async} is the received power level at the BS from a UE in asynchronous mode. Similarly, we can express the Eb/No for synchronous UEs under scrambling code number j as

$$\rho = G\frac{Pj\ sync}{Ptotal - Nj\ sync\ Pj\ sync\ \alpha} \tag{4}$$

where P_{jsync} is the received power level at the BS from a synchronous UE under scrambling code number *j*, and α ε [0, 1] is the orthogonality factor, which expresses the degree of orthogonality between the signals received under the same scrambling code. In a radio channel with marginal time-dispersion and perfect synchronization at the BS, α →1. On the contrary, if the synchronization of the signals received at the BS completely fails due to erroneous adjustment of timing of the transmitted signals or excessive time-dispersion in the radio channel, then α →0.

From equations (3) and (4), the following expressions are obtained

$$Pasync = \rho\frac{Ptotal}{G} \tag{5}$$

$$Pj\ sync = \frac{\rho Ptotal}{G + \rho\ Njsycn\ \alpha} \tag{6}$$

The total received power at the BS can be expressed as

$$Ptotal = Pown + Pother + Pnoise \tag{7}$$

$$Ptotal = Pown(1+i) + Pnoise \tag{8}$$

where P_{own} is the own cell power, P_{other} is the other cell power, and $i=P_{other}/P_{own}$ is the other-to-own cell interference ratio. The own cell power equals

$$Pown = Nasync\ Pasync + \sum_{j=1}^{J} Nj\ sync\ Pj\ sync \tag{9}$$

where J is the number of enabled scrambling code groups within the cell of interest. Combining equations (5), (6), and (9) yields

$$Pown = Ptotal\ \rho\left(\frac{Nasync}{G} + \sum_{j=1}^{J}\frac{Nj\ sync}{G+\rho\ Nj\ sync\ \alpha}\right) \tag{10}$$

An expression for the NR at the BS is subsequently obtained by combining equations (8) and (10),

$$NR = \frac{Ptotal}{Pnoise} = \left\{1-(1+i)\rho\left[\frac{Nasync}{G} + \sum_{j=1}^{J}\frac{Nj\ sync}{G+\rho\ Nj\ sync\ \alpha}\right]\right\}^{-1} \tag{11}$$

For systems where the UEs are not necessarily assumed to be transmitting all the time, an activity factor *v ε* [0, 1] is introduced. Hence, *v*=1 for UEs with constant transmission, while *v*=0.5 is equivalent to transmission during 50% of the time. Assuming that the average activity factor is identical for all the UEs, it can easily be shown that the expression in (11) is generalized to

$$NR = \frac{Ptotal}{Pnoise} = \left\{1-(1+i)\rho\left[\frac{v\ Nasync}{G} + \sum_{j=1}^{J}\frac{v\ Nj\ sync}{G+v\ \rho\ Nj\ sync\ \alpha}\right]\right\}^{-1} \tag{12}$$

B. Theoretical Analysis of Capacity of Uplink Synchronous WCDMA

The capacity in a cell is defined as the sum of the throughput transmitted by every UE in the cell [7]. Hence, the capacity per cell in a synchronous and an asynchronous system equals

$$Casync = Rb\ v\ Nasync \tag{13}$$

$$Csync = Rb\ v\sum_{j=1}^{J} Nj\ sync \tag{14}$$

Respectively, where R_b is the bit rate for a single UE. The capacity gain of uplink synchronous WCDMA can then be expressed as

$$Gsync = \frac{Csync - Casync}{Casync} \tag{15}$$

By carrying out some manipulations, from equations (12), (13), (14) and (15) it is possible to derive the following expression for the capacity gain of uplink synchronization

$$Gsync = \frac{1+i}{\eta}\left[\frac{\eta J}{1+i-\alpha} + \frac{\rho\ v\ Nmax}{G} - (J-1)\right] - 1 \tag{16}$$

where N_{max} is the maximum number of UEs that can be allocated under the same scrambling code, and η*J* is the load factor increase associated with the UEs in scrambling code number J; J and ηJ can be calculated as

$$J = \eta\frac{G+\rho\ v\ \alpha\ Nmax}{(1+i)\rho\ v\ Nmax} \tag{17}$$

$$\eta J = \eta - \frac{(1+i)\rho v Nmax(J-1)}{G+\rho v\alpha Nmax} \tag{18}$$

The expression in (12) is employed to plot the NR in Fig. 4 versus the number of UEs, conditioned on α=0.9, *G*=314 (3.84 Mcps/12.2 kbps), ρ=6.1 dB, *v*=0.5, and *i*=0.6. These parameter settings correspond to a typical micro cellular environment with 12.2 kbps speech users, assuming a chip rate of 3.84 Mcps. Results are presented for cases where all the UEs are either in asynchronous or synchronous mode. The curve labeled "no code limit" refers to the case where *J*=1, independently of the number of synchronous UEs, i.e. corresponding to an infinite number of channelization codes under a single scrambling code.

The other curve for UEs in synchronous mode assumes a maximum of 50 UEs under each scrambling code. For this scenario, UEs are first allocated under scrambling code number one. Once the number of UEs exceeds the maximum number of channelization codes, the second scrambling code is enabled, and so forth. As an example, for 65 synchronized UEs, J=2 with $N^1 sync$=50 and $N^2 sync$=15. It is observed from Figure 4 that the NR increases rapidly for the case where all the UEs are operated in asynchronous mode, while the NR increases slower in the cases with synchronous UEs. This is equivalent to a capacity gain of uplink synchronous WCDMA compared to conventional asynchronous systems. The two NR curves for the synchronous cases are identical up to 50 UEs, where after the curve conditioned on a maximum number of UEs per scrambling code starts to increase much faster. This behavior occurs because the synchronized UEs under different scrambling codes are non-orthogonal.

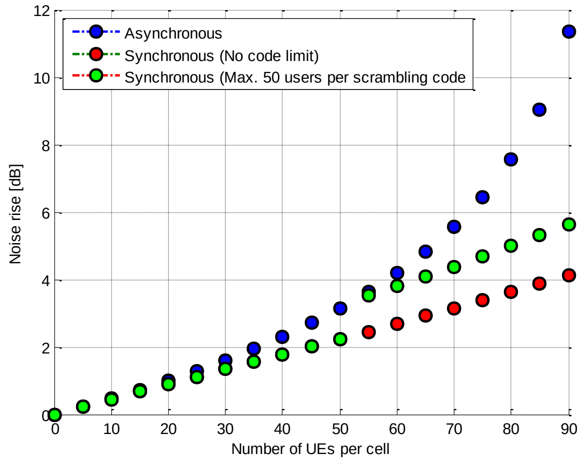

Figure 4. NR as a function of the number of UEs per cell (α=0.9, G=314, ρ=6.1 dB, v=0.5, and i=0.6).

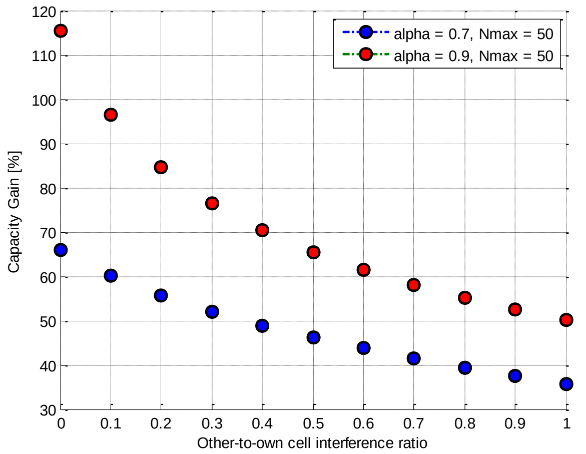

Figure 5. Capacity gain of uplink synchronous WCDMA for a NR target of 4.0 dB

The capacity gain of synchronous WCDMA for a NR target of 4.0 dB is plotted in Fig. 5 versus i for different values of α. The remaining parameters are identical to the ones used in Fig. 4. It is observed that the capacity gain decreases for increasing i. This is due to the fact that only the own cell interference is reduced by introducing synchronous WCDMA, and hence the gain decreases when the other cell interference starts to become dominant. Similarly, it is observed that the capacity gain decreases for decreasing values of α.

III. Synchronization As Capacity Improvement Technique in Uplink of WCDMA

In the previous section, it was shown that uplink synchronization can be a method to reduce the multiple access interference (MAI) by means of exploiting the uplink orthogonality and thereby increase the capacity of WCDMA systems. The performance of uplink synchronous WCDMA has been assessed in terms of the capacity gain relative to an equivalent asynchronous system. The capacity gain has been evaluated theoretically and by means of Matlab simulations for scenarios with different orthogonality factors. The maximum number of available channelization codes turns out to be a major limitation for the capacity gain of an uplink synchronous WCDMA system. Synchronization plays an important role in enhancing the capacity gain of uplink WCDMA system. Orthogonality of codes is directly dependent on synchronization which in turn increases the capacity gain. However, provided that the problems associated with the channelization code shortage can be mitigated, uplink synchronous WCDMA can be demonstrated to provide a significant capacity gain. In WCDMA uplink each user acts as an interference source for other users in the system. However, the demanded traffic grows rapidly, and new capacity enhancement techniques are required in order to satisfy the future needs. The performance of uplink synchronous WCDMA provides a potential capacity gain in the cases where there is no channelization codes restrictions. However, this seems to be one of the major challenges to unleash the full performance potential of synchronized uplink in WCDMA. An immediate solution to solve this problem is to allow the Base Stations (BS) to assign multiple scrambling codes in order to increase the number of available code resources per cell, as each scrambling code is associated with a channelization code tree. However, since signals transmitted under different scrambling codes are non-orthogonal, the practical applicability of this approach is limited. The scheme where the user equipments (UE) are allowed to change their modulation scheme during the transmission has already been proposed in 3GPP for High Speed Downlink Packet Access (HSDPA) in the downlink. A higher order modulation would support transmitting with a higher spreading factor (SF) while keeping the same throughput. To some extent, a similar effect could be obtained by increasing the effective channel-coding rate. The use of a higher SF while keeping the same throughput has the benefit of decreasing the channelization code consumption and thereby improve the capacity of uplink synchronous WCDMA. As discussed below, the problem of limited channelization codes can be minimized if the UEs experiencing a higher propagation attenuation are obliged to transmit with lower order modulation and coding rate, as a higher required Eb/No for these UEs is translated into a much higher inter cell interference in the system.UEs with lower radio propagation attenuation would therefore be allowed to transmit with higher order modulation and coding rate, which, in spite of requiring a higher signal-to interference ratio (SIR), provide a greater throughput.

A. Transmission in WCDMA with Higher Modulation Schemes

As depicted in Fig. 6, the information arriving at the physical layer of a WCDMA transmitter with a bit rate R_b goes through several blocks, which modify the data rate [6]. First, redundant information is added with an effective coding rate $R_{coding;}$ then, the modulator converts every N_b bits into one symbol. Finally, the signal is applied a spreading factor *SF*, acquiring the chip rate R_c.

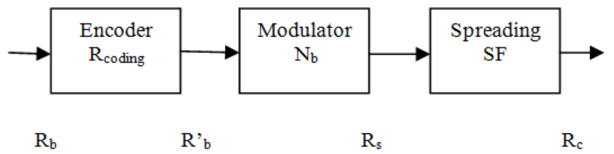

Figure 6. Physical layer transmission in WCDMA

$$Rc = Rb \frac{SF}{Nb.\ Rcoding} \tag{19}$$

where *G* is the processing gain.

In the uplink of the UMTS Terrestrial Radio Access - Frequency Division Duplexing (UTRA FDD) mode, the information associated with every single physical channel is turbo encoded with a rate 1/3 or convolution encoded with a rate 1/2 or 1/3. Puncturing or repetition is used for rate matching. Fig. 7 shows the block diagram of the uplink transmitter after channel coding for one Dedicated Physical Data Channel (DPDCH) and one Dedicated Physical Control Channel (DPCCH) according to 3GPP. The signals are multiplied by the channelization code (C_d for data and C_c for control) and weighted by gain factors (β_d for DPDCH and β_c for DPCCH). The information from these channels is then BPSK modulated. The channels from the same UE are I-Q combined and multiplied by the complex scrambling sequence Sn in order to obtain a signal envelope similar to Quadrature PSK (QPSK) transmissions [7].

An example of an alternative scheme using higher order modulation is proposed in Fig. 8, where the signal associated with the DPDCH is QPSK-modulated before applying the channelization code. The signal associated with the DPDCH is multiplied by a channelization code C'_d with double SF compared to C_d. Both schemes in Fig. 5 and Fig. 6 provide the same bit rate $R_{b,\ d}$ for the DPDCH and $R_{b,\ c}$ for the DPCCH, but the one in Figure 6 uses half of the channelization code resources for the DPDCH. Hence, a higher order modulation than Binary PSK (BPSK) (e.g. QPSK or 8PSK) can support either transmitting with a higher bit rate for the same SF or keeping the same bit rate with a reduced channelization code consumption. The same effect is obtained by increasing the channel coding rate.

Although the use of higher order modulation and/or higher coding rate results in a more efficient use of the channelization code tree, the UEs will require a higher Eb/No except for the case of going from BPSK to QPSK. In uplink synchronous WCDMA, higher order MCSs will therefore be employed only when the benefit of using just one scrambling code compensates for the extra energy required for the transmission.

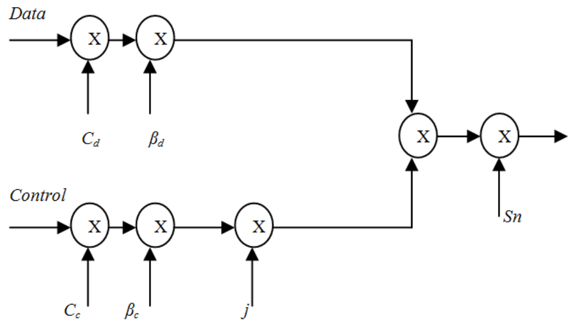

Figure 7. Transmission of data through one DPDCH and one DPCCH according to 3GPP

B. Bit Error Rate Performance Analysis of Higher Order Modulation Schemes

The implementation of high data rate modulation techniques that have good bandwidth efficiency in WCDMA cellular communication requires perfect modulators, demodulators, filter and transmission path that are difficult to achieve in practical radio environment. Modulation schemes which are capable of delivering more bits per symbol are more immune to errors caused by noise and interference in the channel. Moreover, errors can be easily produced as the number of users is increased and the mobile terminal is subjected to mobility [6], [7].

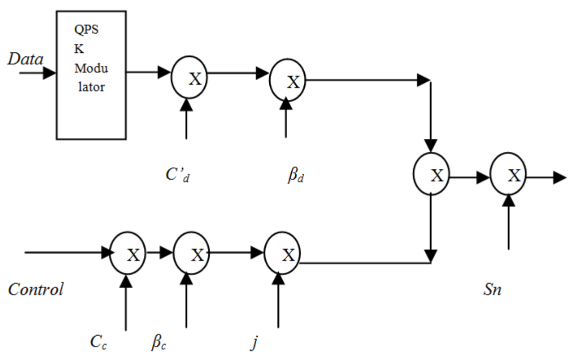

Figure 8. Transmission of data through one DPDCH and one DPCCH employing higher order modulation.

In cellular system, different users have different channel qualities in terms of signal to noise ratio (SNR) due to differences in distance to the base station, fading and interference. Special characteristics of QPSK are twice data can be sent in the same bandwidth compared to BPSK. Also QPSK has identical bit error probability to that of BPSK. Furthermore, similar to BPSK, QPSK can be differentially encoded to allow non-coherent detection. Quadrature Amplitude Modulation (QAM) is a modulation technique where its amplitude is allowed to vary with phase. QAM signaling can be viewed as a combination of Amplitude Shift Keying (ASK) as well as Phase Shift Keying (PSK). The performance of WCDMA system in Additive white Gaussian Noise (AWGN) channel shows that QPSK modulation technique has a better performance compared to that of 16-QAM. Furthermore, similar trend is found when the channel is subjected to multipath Rayleigh fading with Doppler shift.

Fig. 9 shows the comparison of BER vs. E_b/N_0 of various modulation techniques for WCDMA system. QPSK modulation scheme gives better results than QAM modulation in higher order modulation techniques.

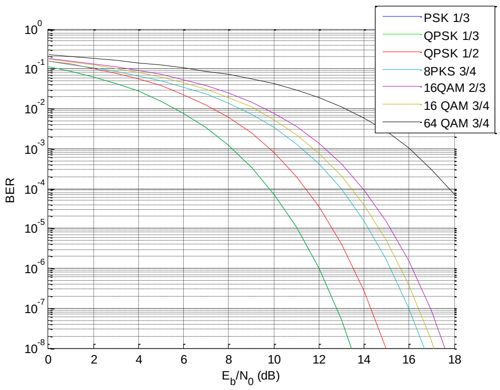

Figure 9. Comparison of BER vs. Eb/N0 of various modulation techniques

If QPSK is used instead of BPSK with the same coding rate for the DPDCH, there is no increment in the required Eb/No, while the code utilization associated with the DPDCH is reduced by half. For the rest of the cases, increasing the coding rate gives a reduction of the CL at the expense of a higher required Eb/No.

C. Performance Analysis of Uplink Snchronous WCDMA with Variable Modulation

The capacity gain of uplink synchronous WCDMA with Variable Modulation (VM) depends on the criterion to assign Modulation Coding Schemes (MCS) to the UEs. This study considers two different approaches to reach an optimum selection of the MCSs so that the noise rise (NR) at the BS is minimized, assuming that all the UEs are capable of operating with uplink synchronous WCDMA and VM:

- In the first one, multiple scrambling codes are allowed per BS, but all the UEs are assumed to adopt the same MCS.
- The second one consists of selecting the optimum combination of MCSs for the own cell UEs, but assuming that only one scrambling code is available at the BS. The theoretical performance of this approach is evaluated by obtaining the optimum values of the number of UEs using every MCS that minimize the NR, i.e.

$$\{N_1 sync, N_2 sync, \dots, N_k sync\} = \min_{\{N1sync,\, N2sync, \dots, NKsync\}} \sum_{k=1}^{k} N\ ksync = 1 \quad (20)$$

where N is the total number of synchronous UEs in the cell, and NR is the noise rise. The optimal parameters in (2) will be obtained by calculating the value of NR for all the possible combinations of {N_1sync, N_2sync,…, $N_K$sync} with the MCSs included in Fig. 7.

The NR is plotted in Fig. 10 versus the number of synchronous UEs per cell for different MCSs by considering the first approach, i.e. assuming that all the UEs use the same MCS. The required Eb/No is obtained by using the values shown in Fig. 7. In this case the maximum capacity gain with uplink synchronous WCDMA and VM is obtained by finding the common MCS for all the UEs in the cell that minimizes the NR. It should be mentioned that the impact of a higher required Eb/No strongly depends on the other-to-own cell interference ratio and the orthogonality factor; e.g. in an ideal single cell case with perfect orthogonality, the NR grows linearly when increasing the number of UEs per cell and there are no unstable states, even when increasing the required Eb/No due to higher order MCSs, as long as only one scrambling code is used.

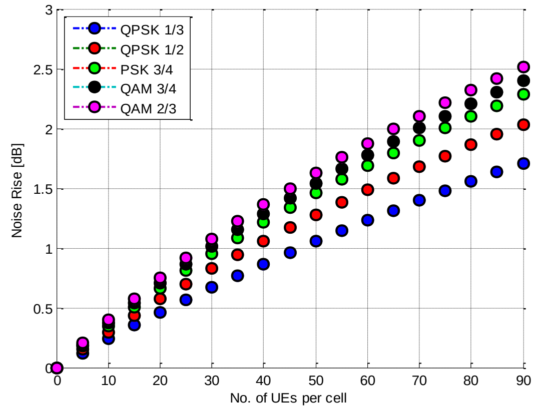

Figure 10. Noise rise versus number of UEs per cell with uplink synchronization assuming the same MCS for all the UEs

Fig. 11 compares the NR obtained with asynchronous uplink, synchronous uplink without VM, and synchronous uplink with VM (assuming optimum selection of a common MCS for all the UEs). It also includes the NR assuming the second approach, i.e. the optimum combination of MCSs for the UEs that minimizes the NR at the BS under one scrambling code. This approach gives a slightly better performance than the first one (using the same MCS for all the UEs).

IV. Conclusion

The performance of uplink synchronous WCDMA has been assessed in terms of the capacity gain relative to an equivalent asynchronous system. The capacity gain has been evaluated theoretically and by means of MATLAB simulations for scenarios with different orthogonality factors. The maximum number of available channelization codes turns out to be a major limitation for the capacity gain of an uplink synchronous WCDMA system.

Synchronization plays an important role in enhancing the capacity gain of uplink WCDMA system. Orthogonality of codes is directly dependent on synchronization which in turn increases the capacity gain. The use of the existing strategies for capacity improvement, such as dual antenna reception at the Node B, and voice activity detection, has been found to decrease the capacity gain of an uplink synchronous WCDMA system. The reason for this is that the channelization code limitation is reached earlier when these capacity enhancing techniques are deployed. However, provided that the problems associated with the channelization code shortage can be mitigated, uplink synchronous WCDMA has been demonstrated to provide a significant capacity gains.

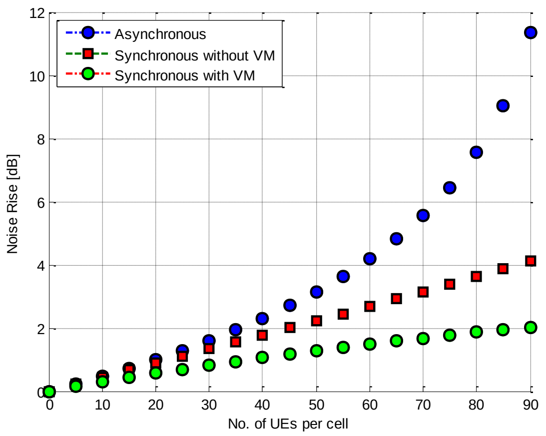

Figure 11. Noise rise versus number of UEs per cell with asynchronous uplink, synchronous uplink without VM, and synchronous uplink with VM.

As discussed in previous section, the channelization code utilization represented the main bottleneck in order to reach a high capacity gain with synchronous uplink. The NR at the BS is known to be a robust measure of the uplink load of a WCDMA system, which is often used by radio resource management (RRM) algorithms to control the uplink load. Variable modulation and coding rate has been presented as a complementary scheme for uplink synchronous WCDMA to decrease the channelization code utilization per UE. The NR gives a better idea of the uplink stability level of the base station (BS) when all the UEs are synchronized.

REFERENCES

[1] 3GPP TS 25.319 V7.7.0 (2009-06). 3rd Generation Partnership Project, Technical Specification Group Radio Access Network; Enhanced uplink; Overall description; Release 7. [Online]. Available: www.3gpp.org.

[2] 3rd Generation Partnership Project, Study report for Uplink Synchronous Transmission Scheme (USTS), TR 25.854, Version 5.0.0, Release 5. [Online]. Available: www.3gpp.org.

[3] 3rd Generation Partnership Project, Multiplexing and channel coding (FDD), TS 25.212, Version 4.2.0, Release 4. [Online]. Available: www.3gpp.org.

[4] A. S. Ramović, "The Modification of WCDMA capacity equation," *16th Telecommunications Forum*, November 2008.

[5] J. O. Carnero and K. I. Pedersen, "Capacity gain of an uplink-synchronous WCDMA system under channelization code constraints," *IEEE Transactions on Vehicular Technology*, vol. 53, no. 4, July 2004.

[6] 3rd Generation Partnership Project, Spreading and modulation (FDD), TS 25.213, Version 4.3.0, Release 4. [Online]. Available: www.3gpp.org.

[7] B. C. Jung, S. S. Cho, and D. K. Sung, "Uplink capacity improvement through orthogonal code hopping in uplink-synchronized CDMA systems," *IEEE Transactions on Wireless Communications*, vol. 8, no. 11, November 2009.

Mridula S. Korde is currently Ph.D. scholar at Electronics Engineering Department, Visvesaraya National Institute of Technology, Nagpur. She is Assistant Professor in the Department of Electronics Engineering at Shri Ramdeobaba College of Engineering & Management, Nagpur, Maharashtra, India. She has received B.E. and M. E. degrees both in Electronics from Nagpur University in 1998 and 2007 respectively. Her research interests are wireless communication, WCDMA synchronization. She has published around 15 papers in the field of wireless communication, image processing in various International/National conferences and Journals.

Dr. Abhay S Gandhi did his BE (Electronic engg.) in 1989 from the VRCE, Nagpur and ME (Telecom) from Indian Institute of Science, Bangalore in 1991. After working for 3 years in industry and education, he joined VRCE, Nagpur as a lecturer in July 1994. He has completed his PhD in August 2002. Currently, he is working as Professor at VNIT.The areas of his teaching (UG and PG) are Analog Communication, Digital Communication, Computer Networks and RFIC design. He has been the coordinator for development of various laboratories in VNIT. He has contributed to the development and maintenance of telecom infrastructure of VNIT.He has published numerous papers in IEEE sponsored international conferences and also in IETE Journal of Research. Recently, he filed patent for a communication device. Several students are carrying out research under his guidance for Ph.D. or M.Tech. (by research) programs.