DYNAMIC SYSTEM LEVEL PERFORMANCE FOR MC-CDMA SCHEME

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***Abstract:* UMTS is expected to provide an initial attempt to support multimedia services to the end user, but still system throughput is limited in high mobility, and large coverage areas. MATRICE (Multicarrier cdmA TRansmission Techniques for Integrated broadband CEllular systems) aims to reach the next step in cellular communications by superseding 3G to provide high bit rate packet based services in moderate to fast mobility environments in a cost effective manner. The air interface is based on TDD MC-CDMA, and we investigate here the impact on system level performance. Furthermore, we employ a dynamic system level evaluation tool, so that global performance statistics also take into account user mobility, and the defined MATRICE scenarios.**

1. Introduction

The MATRICE project aims to provide a feasibility study; to investigate an MC-CDMA air-interface as a potential candidate for beyond3G cellular systems. The motivation for MC-CDMA leads to its ability to support high speed, delay stringent services to the end user, in a cost-effective manner. It promises to fulfill these expectations, by integrating state-of-the-art signal processing schemes to maximise channel throughput such as MIMO technology, advanced Multi-User Detection, and beamforming [1],[2]. In the initial stage, the deployment will target isolated areas, operating in the 5GHz band. Within the MATRICE framework lies some challenging requirements at system level [3][4]: to provide 100Mbps in indoor environments, up to 20 Mbps in urban environments, and up to 10 Mbps at 300km/h. In this paper, we investigate the impact of MC-CDMA chain on system level performance, for the urban operating environment in the presence of real-time dedicated traffic channels. We provide some initial findings in terms of system capacity based on the MATRICE downlink physical layer reference chain operating in TDD mode. We aim to evaluate dynamic system level performance, so that the effects of user mobility, and handover are taken into account to attain a complete and realistic assessment of global system performance. This paper has the following layout: section II describes the system level evaluation tool that supports the evaluation of radio resource management entities, designed to support real time services, and dynamic simulations for the defined test environment; section III considers the link level interface, and the specification of the MATRICE reference link level platform; the simulation results are given in section IV; and finally the conclusion in section V.

2. System Level Evaluation Environment

In this section we recall the simulation environment which includes a model description of the test scenario and the radio resource management entities.

2.1 Test Environment

In this paper, we model an urban mobility environment, which is a subset of the MATRICE scenarios. The test scenario is defined by the following models:

2.1.1. Deployment Model

The cell radius is 300m. The deployment scheme is assumed to be a hexagonal cell layout. Omni-directional antennas are assumed.

2.1.2 Mobility Model

The mobility model for the Vehicular Test environment is a pseudo random mobility model with semi-directed trajectories. The Mobile’s position is updated according to the de-correlation length, and direction can be changed at each position update with probability 0.4, and with a maximal angle for direction update given by 45°. In addition, we assume the mobiles are uniformly distributed on the map and their direction is randomly chosen at initialization. To minimise simulation time, and to benefit from accurate interference modelling, we use a wrap around effect to model user mobility at the cell boundaries. The users may enter or arrive at different cells departing from a single cell according to their direction. Figure 1 illustrates the results from a test simulation with a user moving around a 4-tier cell environment with a 300 m cell radius.

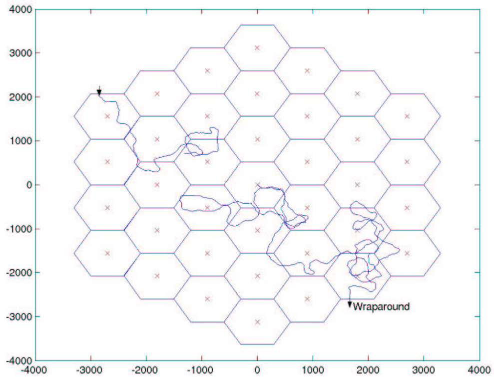

Figure 1: Single user trajectory for urban mobility model

Interference modelling for the cell of interest which is not the centre cell, will take into account the base station, and mobile transmitted powers from sources that are four tiers ways, a subset of these will be from interfering sources that are wrapped around. Furthermore, cell statistics in terms of total throughput, and user QoS can be taken from all cells with confidence, per simulation run.

2.1.3 Propagation channel

We use the path loss model that was defined for the "Vehicular Test Environment" in [5]. This model is applicable to test scenarios in urban and sub-urban areas outside the high-rise core where the buildings are of nearly uniform height. The path loss formula is given by:

$$L = [40(1-4\times10^{-3}\frac{\Delta h_b}{m})]\log_{10}(\frac{R}{km}) - 18\log_{10}(\frac{\Delta h_b}{m}) + 21\log_{10}(\frac{f}{MHz}) + 80dB \tag{1}$$

where R is the base station-mobile station separation, f is the carrier frequency and Δh_b is the base station antenna height, measured from the average rooftop level. Therefore, for a carrier frequency of 5000 MHz and a parameter Δh_b set to 15 m, the path loss expression becomes:

$$L = 136.51 + 37.6\log_{10}(\frac{R}{km}) \tag{2}$$

2.1.3.1 Shadowing

At the system level, we assume the received power to be a slow varying quantity due to the shadowing effects. This phenomena, typically known as “slow fading” is taken into account in received power calculation by multiplying the transmit power by a random log-normal variable. The log of the shadowing variable has Gaussian characteristics with zero mean and a standard deviation σ in dB. The shadowing effect is correlated in distance, therefore the values of the shadowing variable for two positions of the mobile station separated by Δx are correlated. The slow fading process for the mobile user can be described by eqn(3)[4].

$$L_t[dB] = R\times L_{t-\Delta t}[dB] + \sqrt{1-R^2}\times X[dB] \tag{3}$$

Where L_t[dB] is the Shadowing value at time t; $L_{t-\Delta t}$ [dB] the Shadowing value at time t-Δt; X in dB is an independent log-normally distributed random value with mean of zero and standard deviation of σ; $\Delta t = d_{cor}/v$; where v is the user's speed; d_{cor} = The de-correlation length defined as the value of the covered distance Δx, for which the auto-correlation is equal to ½; R is the normalised autocorrelation function of the shadowing.

2.2 Radio Resource Management

We now recall the radio resource management entities that form part of the system level architecture.

2.2.1 Call Admission Control

The objective of Call Admission Control is to regulate the operation of a network in such a way that ensures uninterrupted service provisioning to the existing connections and to accommodate in an optimum way the new connection request. CAC is performed when a mobile station requests communications, and is performed separately for uplink and downlink. This is especially important if the traffic is highly asymmetric; however in this paper we only consider the downlink scenario. Downlink CAC is assumed based on the downlink total transmission power i.e. the new connection is admitted if the new total downlink transmission power does not exceed the predefined target value [6]:

$$P_{total\_old} + \Delta P_{total} < P_{threshold} \tag{4}$$

where the threshold value is set by radio network planning. The total base station transmission power can be presented as:

$$P_{total\_old} = p'_{tb,ctl} + \sum_{x\in cellb} P'_{tb,x} \tag{5}$$

where $p'_{tb,ctl}$ represents the control channel transmission power, and $P'_{tb,x,}$ is the downlink transmission power of cell *b* allocated to mobile *x*. The load increase ΔP_{total} in the downlink can be estimated based on the initial power. The initial power depends on distance from the base station and is determined by the open loop power control algorithm.

2.2.2 Link Adaptation

To maintain user throughput over the wireless channel, we need link adaptation techniques that aim to maintain link quality at the desired level. Link quality is sensitive to the radio conditions, and service requirements, leading to several alternative solutions. For Real time services such as circuit-switched services, voice services, and video conferencing (and less strongly streaming video) require low delay, low jitter, and constant quality. We use CLPC (Close-Loop Power Control) that adapts the average SIR to the desired target level, therefore the scheme compensates for the path loss, and slow fading variations in the received signal, which means that these assumptions must be reflected in the link level scenario; therefore the fast fading effect is modelled, and confined to the link simulations only. The CLPC function is called on every Tpc period. Tpc is chosen to be much larger than the fast fading coherence time and much lower than the shadowing coherence time.

At time $k\times Tpc$, the CLPC function is called for the UE (User Equipment). The CLPC function first checks if the UE is in the receiving state. Then it updates the DL Interference and the DL SIR, using the most recent values of the DL transmission powers, path loss and shadowing. The CLPC function deduces the necessary amount of transmission power P_{new} as a function of the current SIR value, SIR target, and the previous BS transmission power P_t according to [7] in linear scale:

$$P_{new} = P_t \times \frac{SIR_{t\arg et}}{SIR} \quad (6)$$

The calculated transmission power is then bounded in such a way that $P_{new}=\max(P_{min}, \min(P_{new}, P_{max}))$. Before allocating the new transmit power, the BS total transmission power P_{tot} is computed:

If $P_{tot}+P_{new}-P_{old}<P_{maxBS}$ (i.e. the Base Station can provide the required amount of power) then, the new transmission power is allocated: $P_t=P_{new}$.;

If $P_{tot}+P_{new}-P_{old} \geq P_{maxBS}$, (i.e. the Base Station cannot provide the required amount of power), then $P_{new} = P_{old} +P_{maxBS}$. - P_{tot} (the required power is truncated and then allocated).

For the DL CLPC, P_{min} is chosen equal to zero in linear value and P_{max} is chosen equal to the maximum BS transmit power P_{maxBS}.

2.2.3 Handover

Handover is one of the essential features of cellular mobile systems used to maintain user throughput at the cell boundaries. In FDD CDMA based systems, soft handover scheme is implemented, where the new link between a user and the target base station is built before breaking the old link from the source base station. Soft handover improves the quality of service due to the signal diversity provided in both links[8], however, it introduces more interference in the downlink and is more complex to implement in TDD systems due to synchronisation issues. In hard handover systems such as GSM, the user is connected only to a single base at any given time, therefore the connection is broken, before a new link is established. We consider Hard Handover to be more appropriate solution for a TDD MC-CDMA system, at the expense of no handover diversity gain. We now recall the hard handover algorithm employed in the system. The i^{th} averaged Ec/Io from CPICH (Common Pilot Channel) from cell j can be given by:

$$\overline{(Ec/Io)}_{j,i} = \frac{1}{N}\sum_{k=1}^{N}(Ec/Io)_{j,i-k} \quad (7)$$

where we assume N is the filter tap length. However we assume that N is sufficiently large so as to average out the fast fading effect in the channel . When the CPICH of the best candidate cell is better than current serving cell by a quantity **Hyst** (hysteresis value used to prevent immature handovers), the handover will be performed:

$$\overline{(Ec/Io)}_{\max} - \overline{(Ec/Io)}_{ser} > Hyst \quad (8)$$

where $\overline{(Ec/Io)}_{\max}$ indicates the best CPICH among candidate cells and $\overline{(Ec/Io)}_{ser}$ corresponds to the CPICH of current serving cell.

3. Link Level Interface

The link level interface tries to map system level scenarios to physical layer parameters so as to provide cross-layer coherency. A solution can be to have a joint system-link level simulator to provide real-time processing of information bits to provide instantaneous block error rate (BLER) readings, however this would be computationally excessive, and would result in large simulation times in multi-cell, multi-user environments. Therefore typically look-up tables are used based on the average value interface technique, which will map the *average signal-to-interference ratio to the BER statistics*. In this way, we model the effect of the physical layer transmission on user throughput, through statistical tables. This scheme is valid for real-time circuit-switched services, due to following assumptions: the information bit rate is constant; the period of activity of a real time connection is very long when compared with the fast fading coherence time; the Block Error Rate must be constant and equal to the target BLER; for the interference computation, we neglect inter-slot interferences (Only neighbouring cells need to be considered for the interference calculation, we can assume that the signal from the serving cell and the interfering signals arrive quasi-synchronously at the mobile) .

3.1 Link Level MATRICE V.0 chain

We now recall the link level chain that is required to produce the Look-Up Tables (LUT) and the Orthogonality Factor (OF). The MATRICE V0 DL system level simulation chain is given by Figure 2.

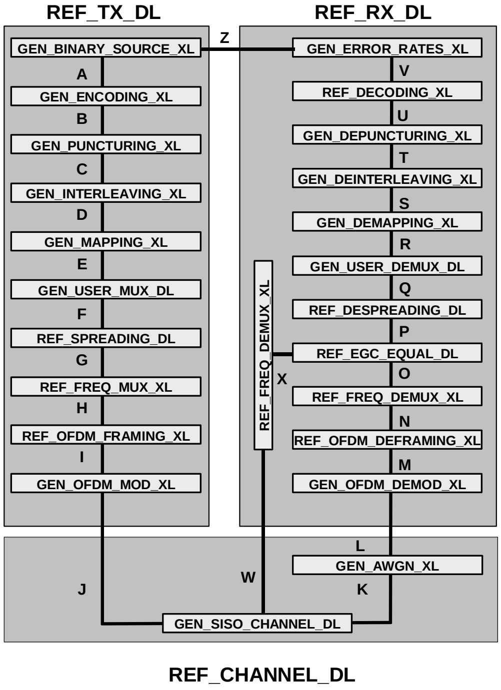

Figure 2: Reference link level simulation chain

Table 1 provides a list of the Physical layer simulation parameters used to generate the LUT.

		V0 set of WP3 system parameters
Channelization bandwidth	B_C	50 MHz
Occupied bandwidth	B_O	41.46 MHz
Sampling frequency	$f_S=1/T_S$	57.6 MHz = 15*3.84 MHz
Slot duration	T_P	0.666 ms

Number of samples per slot	N_P	38400
Number of OFDM symbols per slot	N_S	30
Symbol total duration	T_T	21.5 µs
Guard interval	T_Δ	3.75 µs
UL/DL guard time	T_G	20.83 µs
Coding Rate	R_c	1/2, 2/3, 3/4

Table 1: V0 DL simulation Parameters

We now define the Link Level simulation assumptions that have been used to generate the LUT for our system level simulations: we assume that no Multi-user detection is performed; all downlink users are synchronous but experience multi-path fading; perfect synchronization, and channel estimation; mono-code, and mono slot connection; and a single modulation, and coding scheme is simulated (1/2 code rate, and QPSK modulation is assumed).

3.2 Interference Modelling

In the system level simulations, we consider the following definition for the interference modelling. Consider a mobile M_i, camped on base station B_j, and using the downlink transport channel C_k.(i.e. using a defined set of frequency slots, time slots and codes). The average received power $P_R(M_i,B_j,C_k)$ at the desired mobile M_i , from BS B_j, for the given downlink transport channel C_k is given by the following equation in linear scale:

$$P_R(M_i,B_j,C_k)=\frac{P_T(M_i,B_j,C_k)\times G_{Bj}\times G_{Mi}}{L_{Mi}\times L_{Bj}\times PL_{Mi,Bj}} \qquad (9)$$

where $P_T(M_i,B_j,C_k)$ is the signal power transmitted by BS B_j to UE M_i on transport channel C_k averaged during *Tpc*; G_{B_j} and G_{M_i} are the base-station, and mobile antenna gain respectively; L_{Mi} is the Body Loss or/and in-car Loss of UE M_i; L_{Bj} is the Cable loss of BS B_j; and $PL_{Mi,Bj}$ is the propagation loss between BS B_j and UE M_i (including path loss and shadowing). To compute the average received Interference power of the UE, we need to capture the inter-cell and intra-cell interference in linear scale.

$$I_R(M_i,B_j,C_k)=\beta_1 I_{Intra}(M_i,B_j,C_k)+\beta_2 P_R(M_i,B_j,C_k)+I_{Inter}(M_i,B_j,C_k) \qquad (10)$$

The intra-cell component is given by is:

$$I_{Intra}(M_i,B_j,C_k)=\sum_{M_{intra}\neq M_i} P_T(M_{intra},B_j,C_k)\frac{G_{M_i}G_{B_j}}{PL_{M_i,B_j}L_{B_j}L_{M_i}} \qquad (11)$$

where M_{intra} is a UE connected to BS B_j and receiving on the same set of frequency and time slots as the transport channel C_k, $P_T(M_{intra},B_j,C_k)$ is the corresponding interfering transmit power (transmit power from BS B_j to UE M_{intra} on the same set of frequency and time slots as the transport channel C_k); and β_1 is the Orthogonality factor for intra-cell interference from other UEs other than M_i. The inter-cell interference in linear scale is:

$$I_{Inter}(M_i,B_j,C_k)=\sum_{B_{inter}\neq B_j} P_T(B_{inter},C_k)\frac{G_{M_i}G_{B_{inter}}}{PL_{M_i,B_{inter}}L_{B_{inter}}L_{M_i}} \qquad (12)$$

where $P_T(B_{inter},C_k)$ is the transmission power of base stations B_{inter} other than B_j, on the same set of time and frequency slots than the transport channel C_k; and β_2 is the Orthogonality factor for intra-cell interference from UE M_i. We compute the updated SIR value in linear scale for the current *[(k-1)Tpc; kTpc]*:

$$SIR(M_i,B_j,C_k)=\frac{P_R(M_i,B_j,C_k)}{I_R(M_i,B_j,C_k)+N_0 W_{C_k} F_{Mi}} \qquad (13)$$

Where F_{Mi} is the Noise figure of UE M_i; N_o is the Thermal noise density, and W_{C_k} is the bandwidth occupied by the channel C_k.

3.3 Interface Structure

This leads us to define the following interface structure given by Figure 3

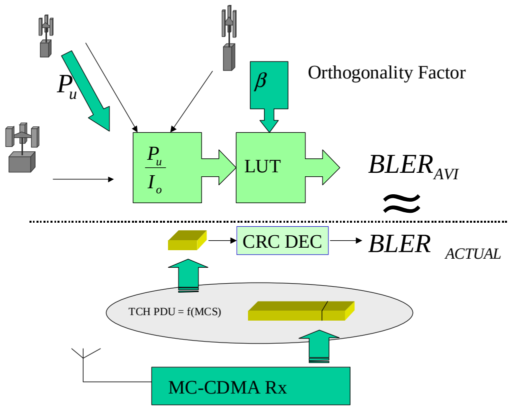

Figure 3:Average Value Interface Scheme

Where **Pu** is the desired signal power received by the considered MS; Io is the total interference consisting of **Ior** (intra-cell interference received power), **Ioc** (inter-cell interference) and noise received power; BLER (Block Error Rate), which is the ratio of erroneous received information data blocks over the total number of received information bits during the overall link level simulation; the orthogonality factor β = f (MCS , environment);

Therefore, it can be said that the average value interface in this instance, is equivalent to the actual average BLER determined in a practical system that uses the cyclic redundancy codes to determine the number of bits in error.

4. Numerical Results

A set of simulations have been carried out to evaluate the impact of MC-CDMA on system level performance. The simulation parameters are given by Table 2

Simulation Parameters	**Setting**
Shadowing de-correlation length d_{cor}	20m (Urban)

Shadowing standard deviation	8dB (Urban)
BER target	10^{-3}
P_{max}	2 w
P_{min}	0 w
$P_{threshold}$	15.8 w
P_{tot}	20 w
SIR_{target}	-10.1477 dB
Handover Hyst	3 dB
MCS1	QPSK 2/3 rate turbo encoder
Information rate per user	55.2 kbit/s
Orthogonality Factor (β)	0.0966
DL Time slots	14
DTCH	30*14 resource units
Simulation Time	2 hours
User Mobility	60 km/h

Table 2. Simulation parameters and settings

To evaluate the system throughput, and efficiency, we investigate the percentage of satisfied users against spectral efficiency, where the former term defines the average number of users that satisfy the following conditions:

- Users that do not get blocked when requesting a connection
- Users that do not get dropped within a session
- Over the call session, the SIR < SIR_{target} for less than 5 % of the call session

The spectral efficiency defines the offered load to the system normalised by the total bandwidth i.e. Kb/s/cell/MHz. Figure 4 shows the % of satisfied users versus spectral efficiency for a DL MC-CDMA TDD system.

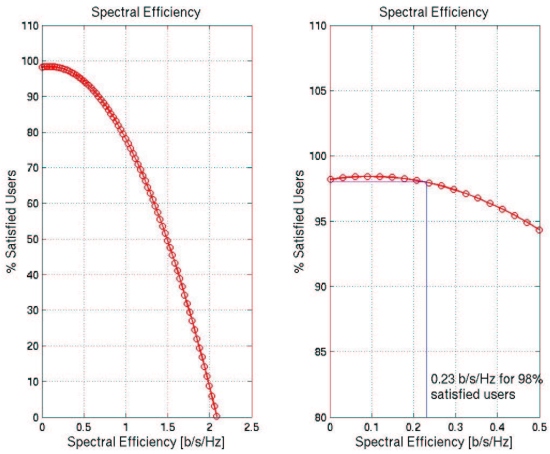

Figure 4 % of satisfied users v spectral efficiency

Figure 4 shows the traditional underlying trend, as we increase the system load, the generated interference increases the average power allocation to the existing connections, and thus causing the system to be interference limited rather than having hard capacity, which is characteristic of CDMA systems. We define the system capacity to be the system load that can support a 98 % user satisfaction ratio. Figure 4 show that a spectral efficiency of around 0.23 can be achieved, which is similar to the efficiency of a UMTS system. This efficiency maps to an actual system throughput of 11.5 Mbps, where the theoretical throughput is constrained to 23.184 Mbps.

Figure 5 addresses the validity of the hard handover mechanism. In the simulations, the handover hysteresis has been chosen so that on average the hard handover takes place around the cell boundary region, whilst keeping the Handover signalling overhead to a minimum, as can be seen in figure 5.

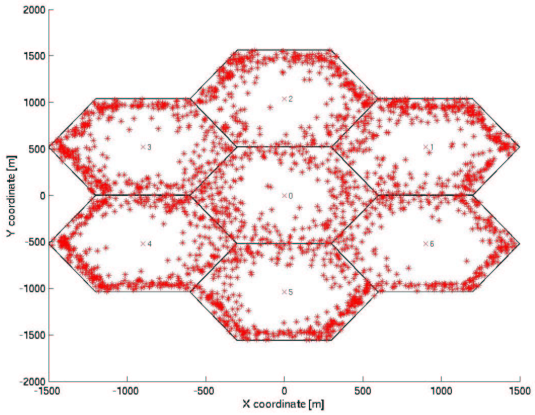

Figure 5 co-ordinate map that shows handover positions

The handover mechanism will have an effect on system throughput, depending on the values chosen for the hysteresis value, and the SIR averaging filter tap length. A handover must happen when the average power required to support the dynamic user would be lower on an adjacent cell when compared to the serving cell, in order to maximise system throughput. However, if we are to consider handover signalling as additional design requirement, then we would need to trade-off between throughput, and signalling overhead leading to the design of adaptive handover algorithms; however this is out of the scope of this paper.

4 Conclusion

In this paper, the impact of the Downlink MATRICE TDD MC-CDMA reference chain on system level performance has been investigated. The simulator architecture encapsulates slow closed loop power control to adapt the DL average SIR variations to the SIR target, and hard handover designed to optimise system throughput only. The effect of call admission control based on downlink available transmission power has also been included to minimise the call blocking rate. Moreover the effect of the MC-CDMA physical layer has been taken into account through an extensive look-up table, that provides information surrounding the average orthogonality factor, and the SIR targets based on QPSK, and 2/3 rate turbo encoder based on frequency domain spreading. It has been shown that the MATRICE system can support large system throughput due to increased available bandwidth, and thus provide at least 11.5 Mbps which can support up to around 200 voice users per cell. This throughput can be supported in an urban environment at 60 km/h. However, these are preliminary findings, and larger throughputs are anticipated, when we take into account the enhanced features of the physical layer that are currently being investigated in the MATRICE project.

Acknowledgements

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References

[1] S. Hara and R. Prasad, “Overview of multicarrier CDMA,” *IEEE Communications Magzine*, pp. 126-133, December, 1997

[2] D. Mottier et al. “Physical Layer Simulation Chain Description”, *IST-2001-32620 MATRICE, D3.1*, Nov. 2002.

[3] J Rodriguez, D. T. Phan Huy et al. , “Radio Link Layer Design for IST MATRICE project”, *IST Mobile and Wirless Communication Summit 2003*, vol II pp847.

[4] D. T. Phan Huy et al.,”Specification of the performance evaluation methodology and the target performance*”, IST-2001-32620 MATRICE, D1.3*, Jan. 2003.

[5] ETSI, "Univeral Mobile Telecommunication System (UMTS); Selection procedures for the choice of radio transmission technologies of the UMTS (UMTS 30.03 version 3.2.0)" *TR 101 112 v3.2.0*, April 1998.

[6] H. Holma and A. Toskla, *WCDMA for UMTS- Radio Access for Third Generation Mobile Communications*, John-Wiley & Sons, 2000

[7] G. J. Foschini and Z. Miljanic, “A simple distributed autonomous power control algorithm and its convergence,” *IEEE Tran. Veh. Tech.*, vol 42, pp.641-646, 1993

[8] A. J. Viterbi et al., "Soft Handoff Extends CDMA Cell Coverage and Increases Reverse Link Capacity," *IEEE J. Select. Areas Commun*., vol. 12, no. 8, pp. 1281-1287, Oct. 1994