Overview of Single Frequency Multipoint Transmission Concepts for HSDPA and Performance Evaluation of Intra-site Multiflow Aggregation Scheme

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***Abstract*—WCDMA based third generation networks are widely deployed and 3GPP is constantly seeking to evolve their performance. It is a well-known problem that reception quality degrades at cell edges. Multipoint transmission from two separate cells can be used to overcome this problem in single frequency deployments. In this paper we make an overview of several techniques for single frequency multipoint transmission, which are under consideration in 3GPP. This study presents the simulation results of Intra-site Multiflow Aggregation scheme where UEs can receive two independent transmissions from separate sectors. The performance of Type 3 and Type 3i receivers is also benchmarked in such scenario. Considerable improvement of radio network performance is demonstrated for users with Type 3i receivers on the borders of the cells without any sensible negative effect for all other users.**

Keywords: HSDPA, Multiflow, Aggreagation, SFDC

I. INTRODUCTION

Currently *Wideband Code Division Multiple Access* (WCDMA) together with General System for Mobile (GSM) networks hold about 90% of mobile telecommunications market. Regardless the introduction of *Long Term Evolution* (LTE) the WCDMA networks show constant subscriptions growth about 40% per year. In the world there are more then 750 millions of *Third Generation* (3G) WCDMA network users in 162 countries. Almost all WCDMA operators have implemented *High Speed Packet Access* (HSPA), i.e. support of peak downlink speed of 7.2 Mbps or higher. Moreover 33% of commercial HSPA networks have already launched Evolved HSPA also called HSPA+ [1]. This wireless broadband standard was firstly defined in *Third Generation Partnership Project* (3GPP) Release 7 and 8 [2]. After Release 10 achievable data rates in downlink direction (HSDPA) are up to 168 Mbps. Nevertheless HSPA networks still need to accommodate huge mobile traffic growth. For that reason 3GPP is constantly seeking for new techniques, which can enhance network performance.

One of the classical problems in cellular mobile networks including HSPA is the degradation of reception quality at the cell edges. Dual-Carrier HSDPA (also known as Dual-Cell HSDPA or DC-HSDPA) technology was firstly defined in 3GPP Release 8 [2]. It proposed effective solution of cell edge problem in multicarrier deployments when 10 or 15 MHz paired spectrum allocations are available to an operator. DC-HSDPA provides enhanced and consistent user experience across the cell especially at the edges where the channel conditions are not favorable and existing techniques such as *Multiple Input and Multiple Output* (MIMO) cannot be used. In the following 3GPP releases this technology was developed even further making it possible to use *Multicarrier* transmissions in combination with MIMO on both carriers and in wider 20MHz frequency band.

At the same time it is rather usual situation when only one 5 MHz frequency band is assigned to an operator. Thus Multicarrier Multi-cell approach cannot be utilized. *Multipoint* HSDPA transmissions from two different *Base Stations* (BS) to mobile users at the borders of corresponding cells can be used to evolve system performance in *Single Frequency* (SF) deployments. This study item was proposed at 3GPP *Radio Access Network* (RAN) *Technical Specification Group* (TSG) meeting in December 2010 [3]. Although LTE is out of the scope of this publication it is necessary to mention that similar transmission scheme was proposed also in LTE-Advanced where it is usually called *Cooperative Multipoint* (CoMP).

In this paper our own research is focused on so called *Intra-site Aggregation* scheme when *User Equipment* (UE) has two independent receiving chains and is capable to receive data simultaneously from two cells of one Node-B. We evaluate the performance of this scheme and conclude that only Type 3i receiver should be used in such scenario. The study is done by means of quasi-static system simulator, in which the most essential physical parameters and radio resource management functions like channel fading, UE scheduling, etc. are modeled in details.

The rest of the paper is organized as follows. Section II contains the description of SF Multipoint concepts for HSDPA. In the following section the most important simulation parameters and assumptions are introduced. In section IV simulation results are presented and analyzed. Finally section V concludes the article.

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II. MULTIPOINT CONCEPTS

There are two main reasons motivating the development of Multipoint HSDPA techniques. Firstly, there is the problem with the reception quality at cell edges when UE is far from the transmitter. In addition cell edge UEs experience stronger interference from neighboring BSs. Secondly, the possibility to use transmissions from several cells provides load balancing function, e.g. UE can utilize the resources from less loaded BSs.

The possibility of Multipoint transmission is determined for every UE according to difference in *Signal to Interference and Noise Ratio* (SINR) for its two strongest BSs. This procedure is analogical to one used to define the *HandOver* (HO) state of UE. If SINR difference is less then predetermined threshold then UE is in HO state and can be scheduled from one or even both BSs.

Multipoint schemes are usually divided in two classes: Intra-site and Inter-site. In the first case UE can receive data only from BSs connected to the same Node-B, i.e. in addition to the strongest primary sector only two other sectors of the same site can be used to assist the transmission (Figure 1). Thus UE should be in *Softer* HO (SofterHO) state. In Inter-cell scenario multipoint transition can occur from every neighboring cell if UE fulfills the requirements mentioned above, i.e. it is in *Soft* HO (SHO) state. The potential gain from the Inter-site realization is higher because usually there are more UEs in SHO state then in SofterHO state. Thus more UEs can benefit from Multipoint transmissions. However from the practical point of view Intra-site implementation is much easier and requires less impact on the network elements. In the case when transmission takes place from two BSs of different Node-Bs changes are needed for all main RAN components: *Radio Network Controller* (RNC), Node-B, and UE as well. For that reason in the rest of the paper we will mainly concentrate on Intra-site scenarios.

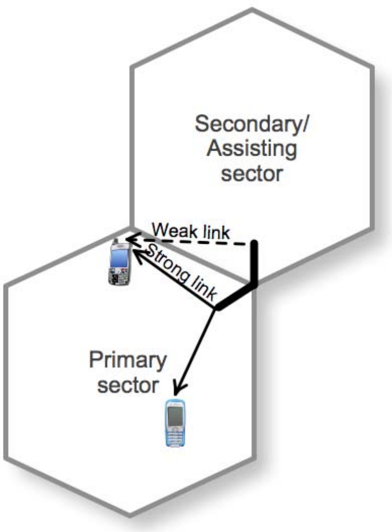

Figure 1. Intra-site Multipoint transmission scheme

To the moment several Multipoint techniques are under consideration [4]

- *High Speed Data-Discontinuous Transmission* (HS-DDTx),
- High Speed Single Frequency Network (HS-SFN),
- Fast cell switching,
- *Single Frequency Dual Cell* HSDPA (SFDC-HSDPA) also called Multiflow Aggregation.

A. HS-DDTx

HS-DDTx technique is not really a multipoint transmission scheme. It does not assume that UEs can receive data from several BSs simultaneously. The main idea is that *High Speed Downlink Shared Channel* (HS-DSCH) is not transmitted every *Transmission Time Interval* (TTI) from the neighboring sectors.

In the early proposals [5] scheduling was organized in such a way that when HS-DSCH was transmitted in sector A, the neighboring sectors B and C did not have active data transmissions (Figure 2). In the following TTI HS-DSCH had to be transmitted only in sectors B, etc. This scheme reduces inter-cell interference and consequently lower transmission power can be used. Later [4] DDTx scheme was modified and became less static. UE at the cell border can be scheduled from each of the sectors (Figure 1). Decision is made every TTI. Data is transmitted from the BS connected through the channel with higher *Channel Quality Indicator* (CQI) whereas in the other sector transmission should not take place at all. Thus the strongest source of interference is removed for UE situated at the cell edge.

It is necessary to note that HS-DDTx is applicable only in low load scenarios when it is possible not to transmit data every TTI, i.e. in initial variant of the scheme BSs could be idle 2/3 of the time. However this approach has easiest implementation and it does not require any changes in the standard. Furthermore, there are no additional requirements for the UE receiver.

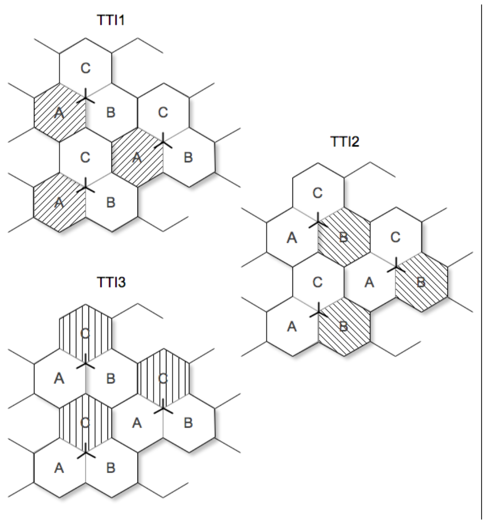

Figure 2. HS-DDTx transmission scheme

B. HS-SFN

According to this scheme UEs, which are in SofterHO state, can receive data from two BSs simultaneously. Both BSs transmit exactly the same data blocks to one UE. Even the same scrambling code should be used during that TTI. In fact this scheme is a transmit diversity scheme. Transmission from assisting cell adds additional power from secondary BS and removes the strongest source of interference. In addition HS-SFN capable UEs benefit from extended spatial diversity. Though this scheme can be applied for legacy UEs with only one receiver some adjustments are still necessary. UE should be able to evaluate weak link channel conditions using the pilots of secondary BS. However transmission will take place using the scrambling code of the primary BS. As a result enhanced receivers should be used [6]. Moreover the transmission with the unusual scrambling code in secondary sector also influences the whole interference picture for all UEs in the primary sector. This fact requires additional adjustments in CQI feedback.

C. Fast cell switching

This technique refers to single point data transmission and also can be used with UEs, which possess only one receiver. According to fast cell switching scheme UE can receive data from only one sector in each TTI whereas sectors can be changes dynamically from TTI to TTI. BSs are chosen in compliance with reported CQI values but in distinction from DDTx scheme it is not required to switch off HS-DSCH in secondary sector. However, the expected throughput gain is not very high (no more than 20%) [7] this approach allows to ensure best conditions for transmission and to balance load when UE cannot be scheduled from the primary sector. It is necessary to mention that this technique is sometimes considered together with SFDC and is called SFDC Switching scheme [8].

D. SFDC, Multiflow Aggregation

The idea of this technique originates from Dual-Cell transmission and gives use to two receivers of DC-HSDPA capable UEs in SF scenario. Proximity of these technologies considerably facilitates SFDC implementation and is based on 3GPP Release 8. The main advantage of this approach originates from the independent use of two receivers. In other words UE can get transmissions from two different sectors aggregating two separate data flows at the same TTI. This fact explains why this concept is called *Multiflow Aggregation* scheme. Although channel conditions for the weak link are worse it might still be possible to increase throughput for Multiflow UEs in SofterHO state. This scheme can also be understood as a spatial multiplexing MIMO scheme, which essentially requires advanced receivers for good performance. Achievable gains in this scenario are the highest among all Multipoint schemes presented above. For that reason we have selected it in this paper to demonstrate the full potential of Multipoint transmission.

III. SIMULATION ASSUMTIONS AND METHODOLOGY

This study has been performed by means of comprehensive quasi-static system simulator, which models HSDPA with a slot resolution. It has been widely used in the past supporting 3GPP standardization work. The simulation tool enables detailed simulation of users in multiple cells with realistic traffic generation, propagation and fading.

A. Quasi-static Simulation Approach

The term "Quasi-static" approach means that UEs are stationary but both slow and fast fading are explicitly modeled. Fast fading is modeled as a function of time for each UE according to the ITU channel profiles which are modified to chip level sampling [9]. Actual simulation area consists of 19 base stations which results into 57 hexagonal cells. Statistics are collected from all cells. Statistical confidence is obtained through running multiple drops, i.e., independent simulation iterations. In each iteration UE locations, fading, imbalance and other random variables are varied. The statistics are gathered and averaged over all drops. *Actual Value Interface (AVI)* mapping is used for mapping link level E_b/N_0 values to frame error rates [10].

B. Traffic and Channel Models

A bursty traffic generation model is assumed, which means that the UEs do not constantly have data in their transmission buffers. Files inter-arrival time is modeled with exponential distribution. File size is also variable and follows lognormal distribution (see TABLE I. for distribution parameters). The data available in the UE buffer is transmitted as fast as it is allowed by the Node-B. Those decisions are made according to *Proportional Fair (PF)* metric allocated to users. Only pedestrian A channel with 3 km/h is studied in this paper.

C. Receiver types

3GPP has specified a number of advanced receiver designs [11]. These designs include Type 1, which uses mobile-receive diversity; Type 2, which uses channel equalization; and Type 3, which includes a combination of receive diversity and channel equalization. An interference aware extension of Type 3 receiver is called Type 3i. The baseline receiver structure for the Type 3i receiver is a *Linear Minimum Mean Square Error* (LMMSE) sub-chip level equalizer, which takes into account not only the channel response matrix of the serving cell, but also the channel response matrices of the most significant interfering cells. This property is extremely important for Multiflow when UEs receive signal from two BSs each of them being in fact an interferer for another. In other words, Multiflow reception is essentially a MIMO reception problem.

In our simulations all UEs use only the most advanced receiver types, i.e. either Type 3 or 3i. The receiver models are ideal in two aspects. Firstly, ideal information on the interference covariance is available. Secondly, for Type 3i, 10 strongest interferers where taken into account. All other BSs are considered as white noise.

D. Simulation Scenario and paramters

The main parameters used in the system simulation are summarized in TABLE I. A hexagonal wrap-around multi-cell layout is utilized. Wrap-around is used to model the interference correctly also for outer cells. This is achieved by limiting the UE placement inside the actual simulation area but replicating the cell transmissions around the whole simulation area to offer more realistic interference situation throughout the scenario. A UE is also able to connect to the replicated cells for example as a part of SHO active set. UEs are created according to a uniform spatial distribution over the whole area. This will result into some cells being more heavily loaded while others can be even empty. 100% of the UEs are SFDC capable but Multiflow is available only for user in SofterHO state.

TABLE I. MAIN SIMULATION ASSUMTIONS

Feature / Parameters	Value / Description
Cell Layout	Hexagonal grid, 19 Node-B, 3 sectors per Node-B with wrap-around
Inter-site distance	1000 m
Carrier Frequency	2000 MHz
Number of UEs/cell	1, 2, 4, 8, 16, 32 UEs dropped uniformly across the system
Reiciver type	Type 3, Type 3i
Channel Model	PA3 Fading across all pairs of antennas is completely uncorrelated.
Soft Handover Parameters	R1a (reporting range constant) = 6 dB, R1b (reporting range constant) = 6 dB
HS-DSCH	Up to 15 SF 16 codes per carrier for HS-PDSCH -Total available power for HS-PDSCH and HS-SCCH is 70% of Node B Tx power, with HS-SCCH transmit power being driven by 1% HS-SCCH BLER
CQI	3 slot CQI delay CQI estimation is ideal CQI Decoding at Node-B is ideal.
Traffic	Bursty Traffic Source Model: - File size: truncated lognormal distribution ($\mu = 11.736$ $\sigma = 0.0$). - Inter-arrival time: exponential distribution, Mean = 5 seconds.
DL Scheduling	A single independent scheduler is assumed. Class A UEs have the highest priority.
Scheduling algorithm	Proportional Fair, forgetting factor 0.001
MP-HSDPA UE capabilities	All MP-HSDPA UEs are capable of 15 SF 16 codes and 64QAM for each cell. Percentage of SFDC-HSDPA capable UEs : 100%.
UE distribution	UEs uniformly distributed within the system.

The SFDC-HSDPA scheduling is considered to be independent. Practically it means that UE is considered like a combination of two separate receivers connected to different BSs and placed to one physical point. Nevertheless Multipoint UEs have one file buffer divided in two flows. BSs take their scheduling decisions depending on the whole load profile in their own cells. However special prioritization algorithm is used. For each cell, two classes of UEs are defined during scheduling [12]:

- *Class A* UEs have this cell as serving, i.e. connected via strongest link.
- *Class B* UEs do not have this cell as serving, i.e. connected via weak link.

Class A UE prioritization means that serving HS-DSCH cell UEs are always scheduled before Multiflow UEs connected to this cell as to a secondary one. This rule is important in high load scenarios. In such a way loss in performance of regular UEs belonging to this serving cell is avoided.

Retransmissions are also taken into account in scheduling algorithm. They always have highest priority over regular transmissions. It works even in the case when retransmission is needed for class B UE whereas active class A UE exists in the same sector.

IV. RESULTS ANALYSIS

Simulation results are presented in this section. Legends in the figures refer to different cases so that

- "Mflow Off" equals to normal HSDPA operation with data transmission only from serving HS-DSCH cell;
- "Mflow Intra" equals to case where UEs in SofterHO can utilize HS-DSCH transmission from multiple cells (depending on scheduling decisions).

The performance is evaluated through mean user throughputs for both all and SofterHO UEs. Gain is calculated as the difference in throughputs divided by the throughput of baseline scenario, i.e. normal HSDPA operation.

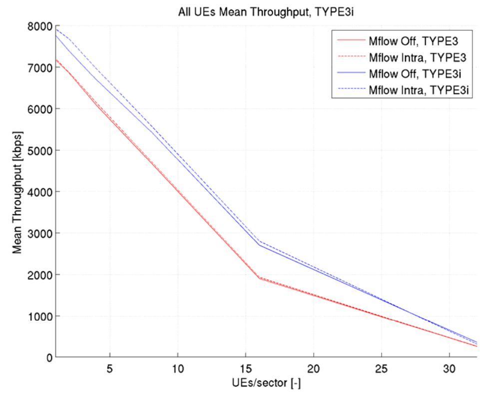

Figure 3. Mean user throughput for all UEs

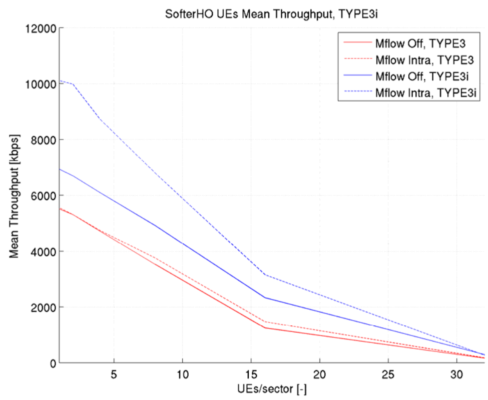

Figure 4. Mean user throughput for SofterHO UEs

Figure 3 and Figure 4 illustrate the mean user throughputs for all UEs and separately for softer HO UEs, respectively using Type 3 and Type 3i receivers. As the figures and TABLE II indicate there is only minor gain or no gain at all using Type3 receiver, but with Type 3i there is clear gain as long as there are less than 32 UEs/sector. The gain is around 45% for SofterHO UEs in 1 UE/sector scenario and decreases from there. Negative gain in 32UE/sector case can be explained by fluctuations in simulation results. The enhancement in performance caused by Type 3i receiver is relatively high even without Multiflow because the interference information is ideally available at the receiver and the bursty traffic model increases the occurrence of a significant dominant interferer.

TABLE II. MEAN USER THROUGHPUTS AND GAINS, SOFTERHO UES

UE/Sector	Type 3			Type 3i		
	Mflow off, Mbit/sec	*Mflow, Mbit/sec*	*Gain, %*	*Mflow off, Mbit/sec*	*Mflow, Mbit/sec*	*Gain, %*
1	5,51	5,55	0,73	6,93	10,11	45,89
2	5,31	5,31	0,00	6,69	9,98	49,18
4	4,71	4,73	0,42	6,01	8,71	43,26
8	3,53	3,76	6,56	4,91	6,79	38,01
16	1,24	1,47	18,55	2,33	3,16	35,62
32	0,16	0,17	6,25	0,29	0,27	-6,90

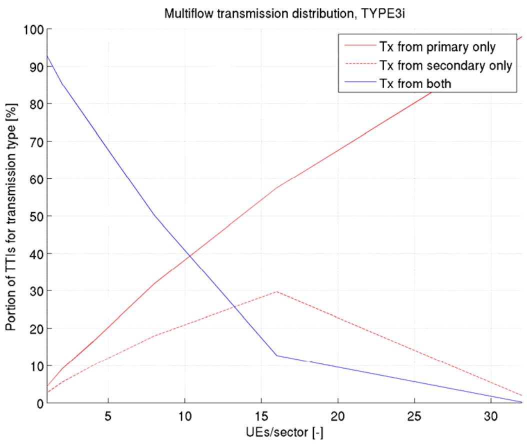

Figure 5. Multiflow transmission utilisation

Figure 5 shows how often Multiflow capable UEs are relatively scheduled from primary, secondary and from both sectors. In low load cases transmission from two sectors happen more than 90% of the active TTIs, but as the load increases primary sector transmissions start to dominate. In 32 UEs/sector case there are essentially no simultaneous two sector transmissions and around 3% of the active TTIs UEs might get scheduled from the secondary sector. This is because of the fact that Class A UEs existing in those sectors prevent Multiflow transmissions.

The results indicate that the Multiflow performance is dependent on the receiver solution. At least in the simulated scenario there is clear performance benefit of assuming ideal Type 3i receivers. Practical performance is largely dependent on the estimation quality of the equalizer parameters such as interference covariance.

V. CONCLUSIONS AND FUTURE WORK

This paper is the first one in the series of publications devoted to Multiflow transmissions. For that reason it contains the overview of main Multipoint transmission techniques for HSDPA. At the same time we present the results of our own simulations for one of the most practically interesting and promising Intra-site Aggregation scheme. It is shown that with Type 3 receiver the achievable throughput gain for users at the cell edges are very low. However, assuming ideal interference aware Type 3i receiver, gains up to 45% in lowly loaded situations can be achieved for the softer handover conditions with favorable traffic load.

In following publications we are going to consider several other scenarios including Inter-site transmissions and vehicular channel models. Further research in this area might be to study imperfections in CQI and enhanced scheduling algorithms.

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