Frame Configuration Impact to the Performance of UTRA TDD System

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Abstract - In this paper we consider the performance of a UTRA TDD system with various slot configurations. UTRA TDD supports flexible and dynamic channel allocations thus it can be configured to different service needs. Uplink and downlink transmissions have different characteristics and in this study we are concentrating on the requirements for symmetrical services in dedicated channels. Effect of number of beacon channels per radio frame and effect of different uplink and downlink partitioning to TDD system capacity are analyzed with dynamic system level simulator. Although this study is limited to circuit-switched data service these findings can be used as a starting point when building up mixed traffic scenarios with asymmetrical services.

I. INTRODUCTION

Standardization of the 3rd generation mobile radio system UTRA (UMTS Terrestrial Radio Access) has been ongoing in 3GPP (Third Generation Partnership project) [1] since 1999. The time division duplex mode (UTRA TDD) is intended to operate in the unpaired spectrum band. The UTRA TDD mode combines time division (TDMA) and code division multiple access (CDMA) schemes into TDD-CDMA, and hence the signals of different users are separated both in time and code domain [2]. For spectrum efficient operation, UTRA TDD takes advantage of power control (PC) and dynamic channel allocation (DCA), which has been recently addressed in [7]. Also other radio resource management (RRM) algorithms, such as handover (HO), admission control (AC), load control (LC) and packet scheduling (PS) are utilized in UTRA TDD. The suitability of the uplink power control scheme and the handover algorithm in UTRA TDD network was evaluated in [3], [4] and [5] and the effect of downlink power control algorithm to system capacity was studied in [6].

The performance of UTRA TDD network is evaluated by using an advanced UTRA TDD system level simulator presented in [8]. The simulator models both inner and outer loop power control, handover, dynamic channel allocation, measurements and involved errors in details. Further it is assumed that all the cells are chip synchronized for the best possible operation and coordination.

This paper is structured as follows. Principles of the UTRA TDD frame and different time slot configurations are presented in Section II. Modeling of RRM is discussed in Section III and simulation assumptions are introduced in Section IV. Simulations results are presented in Section V and finally conclusions are drawn in Section VI.

II. FRAME CONFIGURATION

In UTRA TDD radio frame is 10 ms long and it is divided to 15 slots each of which can be allocated to uplink or downlink. With this kind of flexibility UTRA TDD can be adjusted for different asymmetric traffic needs. Especially asymmetric services are important since future service needs such as Web browsing, video on demand and multimedia are heavily concentrated on downlink traffic. The TDD mode can be used to provide asymmetrical services with flexible and dynamic way by enabling different switching point configurations and by usage of Dynamic Channel Allocation (DCA) algorithm. In this paper we take a look at the different TDD frame configurations with circuit-switched data traffic to produce guidelines for future services with mixed traffic conditions with asymmetrical services.

In UTRA TDD a variable time offset between downlink synchronization channel (SCH) and system slot timing is used to make it possible to detect synchronization channels of different cells within one time slot. The SCH can be mapped either to time slot number n = 0…14 or to two time slots n and n + 8, where n = 0…6 [2]. For the cellular usage two synchronization channels per frame is preferred to enable necessary monitoring for proper intersystem handover from GSM or UTRA FDD to UTRA TDD [16].

The Primary Common Control Physical Channel (PCCPCH) is always transmitted in the first SCH slot within a frame and uses predefined channelization code and midamble. The PCCPCH is a fixed-rate downlink physical channel used to carry Broadcast Channel (BCH). It is transmitted with fixed power, the value of which is also broadcasted to all terminals providing reference for terminal made measurements e.g. path loss measurement for uplink power control. In addition to PCCPCH also the Secondary Common Control Physical Channel (SCCPCH) function as a beacon channel as defined in [13]. The SCCPCH is used to carry Forward Access Channel (FACH) and Paging Channel (PCH) [13].

The Physical Random Access Channel (PRACH) is used for logical Random Access Channel (RACH) for terminals to transmit messages randomly to acquire access to the network.
In this study effects of different frame configurations to UTRA TDD system capacity are studied with dynamic system level simulator. Studied frame configurations are presented in Table 1. In different configurations number of uplink and downlink slots are varied and in addition to that also effect of number of beacon channels per radio frame are analyzed. Effect of PRACH is not taken into account in this study.

### Table 1 Studied frame configuration setups.

<table>
<thead>
<tr>
<th>Slot</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>PCCPCH</td>
<td>PCCPCH</td>
<td>PCCPCH</td>
<td>PCCPCH</td>
</tr>
<tr>
<td>1</td>
<td>Uplink</td>
<td>Uplink</td>
<td>Uplink</td>
<td>Uplink</td>
</tr>
<tr>
<td>2</td>
<td>Uplink</td>
<td>Uplink</td>
<td>Uplink</td>
<td>Uplink</td>
</tr>
<tr>
<td>3</td>
<td>Uplink</td>
<td>Downlink</td>
<td>Downlink</td>
<td>Downlink</td>
</tr>
<tr>
<td>4</td>
<td>Uplink</td>
<td>Downlink</td>
<td>Downlink</td>
<td>Downlink</td>
</tr>
<tr>
<td>5</td>
<td>Uplink</td>
<td>Downlink</td>
<td>Downlink</td>
<td>Downlink</td>
</tr>
<tr>
<td>6</td>
<td>Uplink</td>
<td>Downlink</td>
<td>Downlink</td>
<td>Downlink</td>
</tr>
<tr>
<td>7</td>
<td>Uplink</td>
<td>Downlink</td>
<td>Downlink</td>
<td>Downlink</td>
</tr>
<tr>
<td>8</td>
<td>Downlink</td>
<td>SCCPCH</td>
<td>SCCPCH</td>
<td>SCCPCH</td>
</tr>
<tr>
<td>9</td>
<td>Downlink</td>
<td>Uplink</td>
<td>Uplink</td>
<td>Uplink</td>
</tr>
<tr>
<td>10</td>
<td>Downlink</td>
<td>Uplink</td>
<td>Uplink</td>
<td>Uplink</td>
</tr>
<tr>
<td>11</td>
<td>Downlink</td>
<td>Uplink</td>
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<td>Downlink</td>
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<tr>
<td>12</td>
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<td>Downlink</td>
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<td>13</td>
<td>Downlink</td>
<td>Downlink</td>
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</tr>
<tr>
<td>14</td>
<td>Downlink</td>
<td>Downlink</td>
<td>Downlink</td>
<td>Downlink</td>
</tr>
</tbody>
</table>

### III. Modeling of RRM

Basic modeling of dynamic TDD system simulator has been presented in detailed level in [4] and [7], thus here we briefly present handover and DCA modeling, which are important for these frame configuration studies.

#### A. Handover model

The handover delay that used in the simulations is combined the UTRAN and UE processing delay that is modeled as lump delay. This is a parameter in the simulations. Figure 1 shows the signaling that is used for handover. All the signaling and processing delays are modeled as one delay element at UTRAN side to encapsulate the functionality from UE air interface point of view.

![Handover model](image)

Figure 1 Handover model used in the simulations. The signaling and processing delay in UTRAN side is modeled as lump delay.

Downlink PCCPCH RSCP measurement is used as a handover criterion and reporting is based on event 1G [9]. The event 1G is modeled according to [10]. No errors are assumed for RSCP measurement and handover hysteresis is set to 5 dB. Two different handover delay values are evaluated in the study and they are namely RRC round trip signaling delay and 2.5 times the RRC round trip signaling delay. The derivation of RRC round trip signaling delay is based on guidelines for packet switched and circuit switched user data for 95% quantile in document [11]. The RRC control signaling is by nature packet based as the interval of 1G messages is random, but the Dedicated Control Channel (DCCH) provides real time characteristics for the message transport. The used RRC round trip signaling delay is 100% quantile for the UE population. The used handover model and the RRC round trip delay incorporates the requirements set for minimum and maximum handover interruption time in [10]. The selected parameters are not optimized for capacity rather than they represent reasonable assumptions for practical operation and the handover parameter setting is kept constant for the simulations.

#### B. Dynamic Channel Allocation modeling

DCA algorithm is divided to two parts where slow DCA allocates resources to cells and fast DCA to bearer services. Fast DCA uses cell related preference list as an input from slow DCA. In these studies cell related preference list is given as parameter and it is similar to Table 1, where directions for each slot is given. All base stations use same preference list to concentrate this study to frame configurations rather than DCA algorithm. For this reason also random slot allocation is used in fast DCA algorithm.

### IV. Simulation Assumptions

The simulated scenario is indoor environment that is presented in Figure 2. Four base stations that are placed in office rooms of the building are assumed. Indoor model physical parameters can be found from Table 2.

![Indoor environment](image)

Figure 2 Used indoor environment and corresponding pathloss map.

The indoor path loss model expressed in dB is in the following form, which is derived from the COST 231 indoor model [14]:

\[
L_{\text{pico}} = 37 + 20 \log(R) + \sum_{i=1}^{n} k_w L_{w_i} + 18.3n^{(n+1)/2}/(n+1)-0.46
\]

where \( R \) is transmitter-receiver separation given in meters, \( k_w \) is number of penetrated walls of type \( i \), \( L_{w_i} \) is loss of wall type \( i \) and \( n \) is number of penetrated floors. One type of internal walls is considered with a loss factor of 6.9 dB.
With simulations minimum coupling loss between different transmitters and receivers is assumed to be 38 dB. Slow fading deviation of 6 dB is used and correlation of 5 meters is assumed for the slow fading process. The used channel model is Case 1 given in [12] with 2 Rayleigh faded multipath components that relative strengths are 0 dB and -10 dB. System noise for the mobile stations is assumed to be -103 dB and for base stations -99 dB.

Table 2 Indoor model physical parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building size</td>
<td>100 x 100 m</td>
</tr>
<tr>
<td>Number of floors</td>
<td>1</td>
</tr>
<tr>
<td>Room size</td>
<td>20 x 20 x 3 m</td>
</tr>
<tr>
<td>Number of rooms</td>
<td>20</td>
</tr>
<tr>
<td>Corridor size</td>
<td>10 x 100 x 3 m</td>
</tr>
<tr>
<td>Number of corridors</td>
<td>2</td>
</tr>
</tbody>
</table>

The simulated service is 12.2 kbps circuit switched service with voice activity of 100 %. UMTS 30.03 [15] mobility model is used. Mobile speed is 1.0 m/s and ratio of mobiles at office rooms is 80 %. Mean office stationary time for mobiles is 30 seconds.

The performance of the network was measured by the rate of satisfied calls. This is defined as

\[ r_{satisfied} = \frac{N_{good}}{N_{ended} + N_{blocked} + N_{dropped}} \]

where \( N_{good} \), \( N_{ended} \), \( N_{blocked} \) and \( N_{dropped} \) are the numbers of good, ended, blocked and dropped calls. In the simulations, only the calls, which start and end during the simulation time horizon, are considered, the number of which is \( N_{ended} \). Once a call ends it is classified as a good/bad quality call or a dropped call. In these simulations ended call was considered as a bad quality call if more than 2 percent of the transmitted frames were erroneous. Otherwise it was considered as a good quality call. Dropping of a call is done if 50 consecutive erroneous frames exist. Blocked calls are those who are not served at all due to the unavailable resources.

V. SIMULATION RESULTS

UTRA TDD system uplink and downlink capacities with different frame configurations presented in Table 1 are analyzed with following simulations. Uplink capacity with frame configuration called Case 1 in Table 1 and with RRC round trip delay defines the reference load at 98% satisfied rate \( (r_{satisfied}) \). The system load in the rest of the cases is shown relative to this reference case. The simulation elapses 4000 seconds.

A. Uplink capacity

Frame configuration has impact to TDD system uplink capacity. Two beacon time slots/frame with RRC round trip delay improves the average uplink time slot capacity 17% as seen in Figure 3. The uplink time slot capacity with RRC round trip signaling delay depends only on the number of beacons in the frame.

With 2.5 times RRC round trip signaling delay uplink capacity depends on number of uplink time slot/frame as seen in Figure 4. The time slot capacity is more sensitive to the number of beacons, but there is increase in the time slot capacity with 2 beacons up to 40 %.

Based on these simulation results it is recommended to use two beacons per frame instead of one. From Figure 5 it can be seen that two beacons per frame improves uplink capacity 19 % with 2.5 times the RRC round trip signaling delay. When the handover delay is equivalent to RRC round trip signaling then there is only marginal BS capacity gain, but no capacity is lost by allocating one DPCH timeslot to SCCPCH use.

Figure 3 Uplink satisfied rate of different frame configurations with RRC round trip signaling delay for handover.

Figure 4 Uplink satisfied rate of different frame configurations with 2.5 times RRC round trip signaling delay for handover.

Converting one uplink time slot to beacon increases uplink time slot capacity via power control and more than compensate the lost time slot. With two beacons and 6 uplink slots decreasing handover delay from 2.5 times to the RRC round
trip signaling has only minor improvement to capacity at 98% satisfied rate. In other asymmetric configurations there is noticeable, up to 30% difference in the capacity caused by the additional handover delay in the TDD system. This applies especially to cases where very few uplink time slots per frame are used.

Figure 5 Uplink capacity/BS at 98% satisfied rate with different handover delay and frame configuration.

### B. Downlink capacity

The downlink satisfied rate with different frame configurations and handover delays is presented in Figure 6 and Figure 7. Downlink capacity/time slot is less than uplink capacity, but downlink is better behaving because capacity does not drop so fast. When the number of downlink time slot/frame is increased over 7, there is noticeable change in the average downlink time slot capacity and system behavior is rather stable with smaller handover delay. In case of 2.5 times the RRC round trip signaling delay similar behavior is observed with 9 downlink time slots/frame.

As seen in Figure 8 downlink has more squared type dependency on number of time slots with longer handover delay. The behavior is not anticipated as the downlink power control was assumed to serve all the timeslots the same.

The delay affects the capacity when there are more than 7 downlink time slots allocated per frame and the difference in capacity is increased from 5 to 20%. The UTRAN delay has a noticeable impact to the system capacity and the delay should be minimized.

Figure 7 Downlink satisfied rate of different frame configurations with 2.5 times the RRC round trip signaling delay for handover.

Figure 8 Downlink capacity/BS at 98% satisfied rate with different handover delay and frame configuration.

### C. Uplink and downlink capacity difference

In Figure 9 capacity difference at 98% satisfied rate between uplink and downlink is presented. Downlink is limiting link direction if less than 8 downlink slots is allocated in frame. Otherwise uplink is limiting link direction. Allocating a RACH time slot can be used to minimize link direction imbalance. Best link balance between uplink and downlink is
achieved with two beacons, 6 uplink and 7 downlink slots independent of handover delay.

![UL/DL capacity difference of frame configurations at 98% satisfied rate with 2.5 and one times the RRC round trip signaling delays.](image)

**VI. CONCLUSIONS**

In this paper we analyzed UTRA TDD system performance with different frame configurations. Based on these simulation results it can be recommend that two beacon channels per frame should be used from system capacity point of view. By using two beacon channels per frame uplink capacity can be increased which more than just compensates the loss of one time slot for DPCH. In addition to that there is also an additional capacity in SCCPCH slot and necessary monitoring can be performed for proper intersystem handover from GSM or UTRA FDD to UTRA TDD.

With smaller studied RRC round trip signaling delay uplink behaves almost as in ideal case, but with 2.5 times longer delay for the handover it suffers from increased interference, thus the number of uplink time slots has clear impact to the system capacity. Downlink performance was found to be more sensitive to delay than uplink.

**REFERENCES**