Adaptive Switching Point Allocation in TD/CDMA Systems

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Abstract – This paper proposes a dynamic channel allocation strategy which takes advantage of the *Switching Point* (SP) positioning, which is one of the features in the *Time Division Duplex* (TDD) transmission mode. A switching point is where the transmission changes direction from downlink to uplink and vice-versa. By placing the switching point within a transmission frame dynamically, a TDD system can provide flexible uplink and downlink capacity to accommodate varying asymmetric traffic in each direction. The proposed algorithm is evaluated by means of simulation and the results are compared to that of system configured with other allocation algorithms.

I. Introduction

Multimedia is expected to dominate future internet traffic, which means there will be more traffic in downlink than in uplink direction [1]. The asymmetric traffic characteristic drives the need of a communication system that can provide flexible downlink and uplink capacity without losing the overall bandwidth efficiency. In mobile communication, a TDD system is such a system.

In a TDD system, since a *timeslot* (TS) can be used either for downlink transmission or uplink transmission, it is possible for a network operator to assign TS to suit the traffic ratio. But in real world, this traffic ratio is impossible to predict beforehand, and it is also not constant over time. In addition, overlapping TS configurations (due to different traffic demand) among neighbouring cells can also cause interference problems as depicted in figure 1 and 2 as example. Suppose there are 8 TS within a transmission frame. The first *Base Station* (BS) uses TS 4 for downlink while the second BS uses the same TS for uplink. From the point of view of a *User Equipment* (UE) which belongs to BS 1 and is receiving data on TS 4, it is also receiving interferences from BS 2's UE transmitting on that TS as well. This is known as UE-to-UE interference. Conversely, BS 2 will not only receive signals from its own UE, but also additional interference from BS 1's downlink signal on TS 4. This is referred to as the BS-to-BS interference [2][3]. To cope with the interference problems and varying traffic load, a TDD system needs an intelligent channel allocation algorithm that can coordinate TS assignment among BS in the system to avoid excessive interference.

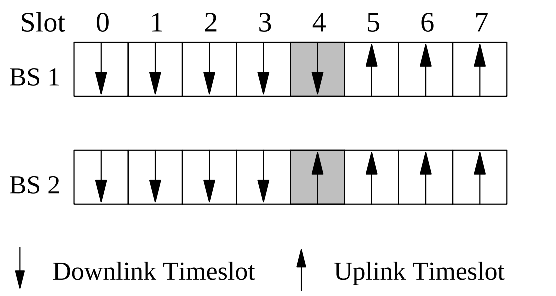

Figure 1: Example of overlapping timeslot configuration between two neighbouring base stations.

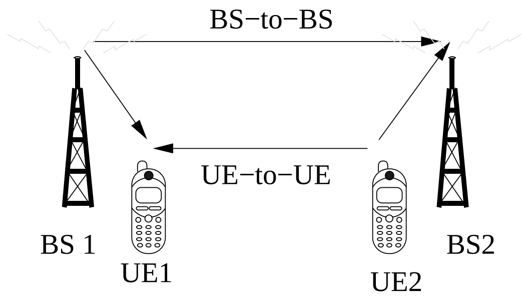

Figure 2: UE-to-UE / BS-to-BS Interference.

A *Code Division Multiple Access* (CDMA) system's capacity is limited by the interference. The BS-to-BS and UE-to-UE interference generated by asymmetric switching point can become a severe limiting factor. This paper investigates in particular an algorithm in TDD mode of *UMTS Terrestrial Radio Access* (UTRA-TDD), which uses *Time Division/ Code Division Multiple Access* (TD/CDMA) technology. In UTRA-TDD, there are 15 TS per transmission frames. Users within the same TS are separated from one another by means of different codes. Up to 16 codes are allowed per TS. A *Resource Unit* (RU) can be identified by a TS and code combination. There are total of 240 RU per frame. A *Switching Point* (SP) indicates a location within a frame where the transmission changes direction from uplink to downlink and vice-versa. Although within a transmission frame, one or more SP are allowed, the algorithm presented in this paper assumes only a single switching point per frame.

II. Channel Allocation Strategies

Three channel allocation strategies are investigated in this paper: *Fixed Channel Allocation* (FCA), Algorithm based on *Timeslot Scoring* (TScoring), and *Adaptive Switching Point Allocation* (AdaptiveSP).

In FCA [4], channels are randomly assigned to connections. Uplink and downlink capacity can be parameterised during the system start-up time by specifying the amount of uplink and downlink timeslots. But during the system operation, no switching point movement is allowed. No resource re-allocation is possible. This strategy is used as a basis for performance comparison.

The TScoring strategy, presented in [4], is a distributed allocation algorithm. The basic idea behind TScoring is trying to locate the best TS within a frame considering interference and how many RU each TS has to offer. The algorithm has been modified slightly and can be summarized as followed:

1. The uplink and downlink capacity ratio can be specified during the system start-up phase, but the switching point cannot be moved afterward. Each service type has its own predefined uplink and downlink interference requirements. This is due to different Q*uality of Service* (QoS) requirements. For example, a speech connection can tolerate more interferences than a packet connection.
2. During the connection establishment, uplink and downlink interferences are measured for each timeslot.
3. Measured values in (2) are compared to the predefined thresholds in (1). If a measured interference is lower than the threshold, and if the slot has at least once free RU that slot is then given 16 points. Otherwise the slot is marked as unusable Scoring is done separately for uplink and downlink. A connection is blocked when all slots are marked as unusable.
4. For each free RU in a TS, an additional point is given to that slot. For example, 4 points are added to a TS's score, if the TS has 4 available RU. Because there are only 16 codes per TS, the highest score which can be given is 16. This step is important for packet service because more RU means higher throughput.
5. In the end, the TS with the highest score is picked out for each direction. (In this paper, a single slot allocation is allowed.) If there are many slots with the same highest score, the slot with the lowest interference will be chosen.

AdaptiveSP strategy shares the same core algorithm as TScoring with an extension to support movement of a single adaptive switching point. This strategy normally follows steps 1-5 of TScoring. However, if a connection is blocked in step 3, the algorithm will try to free up the TS that belongs to the opposite direction at the border between uplink and downlink. If the relocation is successful, the new free slot will be used for the new connection. This is better shown in an example:

- Suppose the TS 0 to 7 are being used currently for downlink and TS 8 to 14 for uplink. A new connection has arrived.
- AdaptiveSP uses its TScoring core algorithm and tries to allocate resource in downlink for this connection. However it fails in step 3 due to high interference in all TS 0 to 7 or no more resource is available.
- AdaptiveSP tries to get more downlink capacity by freeing up the uplink TS 8, which locates at the border between uplink and downlink. All the uplink connections which are assigned to TS 8 have to be reassigned uplink resources in uplink slots. AdaptiveSP finds a suitable uplink slot for each of these connections among the remaining uplink slots (TS 9 to 14) using the TScoring.
- If all existing uplink connections are relocated successfully, the TS 8 can be used as an additional downlink slot. The switching point is moved. The new connection can now use slot 8 for downlink.
- If uplink resource is also needed, AdaptiveSP will search among TS 9 to 14 for an uplink slot. If no uplink slot is found, the new connection will be blocked. (It does not make sense to try to free the TS 8 because it has just been freed for downlink usage.) Otherwise, the new connection can be established.

III. Simulation and Evaluation Criteria

Simulations are carried out in a small version of Manhattan Grid urban environment specified in the UMTS 30.03 specification [6]. This scenario consists of 12 BS, covers the total area of 1320 m x 1320 m. The system has a single bandwidth of 5 MHz. The system operating frequency is in 2GHz range. The propagation model, traffic and mobility model, and other parameters are also taken from [6].

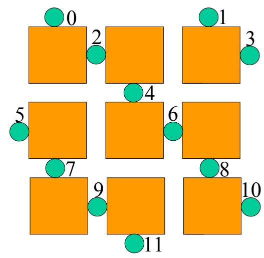

Figure 3 – Small Manhattan Grid scenario with 12 BS

Since the CDMA system capacity is limited by interference, the standardized SIR-based power control specified in [7] is enabled to minimize BS-to-BS and UE-to-UE interference.

Both speech and packet mobiles exist in the system. A speech call needs 1 RU in uplink and 1 RU in downlink. A packet call requires 4 RUs in downlink. The maximum throughput of a packet call according to this configuration is 92.8 Kbps. There are a number of criteria to look at when comparing the performance of each allocation algorithm. One criteria is called *Satisfied User Criteria* (SUC), which is specified in [6]. SUC for speech call which can be summarised as follows:

1. Call is not blocked or disconnected during handover.
2. Channel has sufficiently good quality ($BER < 10^{-3}$), more than 95% of the connection period.
3. User is not disconnected. Disconnection occurs when $BER > 10^{-3}$ more than 5 seconds

A packet call is considered satisfied, if a user is not blocked or dropped and the active session throughput is above 9.28 Kbps (i.e. greater than 10 % of the maximum 92.8 Kbps throughput)

IV. Results

The simulations are carried out in two types of scenarios. In the 1st scenario, every BS in the system carries the same amount of traffic, and the traffic is downlink-biased. In the 2nd scenario, some BS carry more traffic than the rest (Hotspot). The traffic is also downlink-biased.

A. Equally Distributed Traffic Scenario

1. In this scenario, the overall traffic ratio is downlink-biased. The downlink-to-uplink traffic ratio is set to 3-to-1. Half of the overall traffic will be speech service while the remaining half belongs to packet service. Every BS is loaded with equal traffic, ranging from 50%-80%. (At 50% load, calls that arrive will take up 120 RU out of 240 RUs within a transmission frame on average.) This scenario is to test the performance of each channel allocation algorithm under different load levels.

Figure 4 shows the overall percentage of satisfied users in the system at different system loads. The x-axis shows the load of the system in percent. The AdaptiveSP series shows the system performance when AdaptiveSP algorithm is used. The TScoring11 series represents the system when TScoring algorithm is used and the number of downlink:uplink slots are 11:4. This ratio is approximately the same as the traffic ratio of 3:1. The TScoring8 is identical to TScoring11 except the downlink:uplink slots are 8:7, which is roughly 1:1. This does not suit the traffic ratio of 3:1. The FCA8 series represents the fixed channel allocation with 8:7 downlink-to-uplink slots.

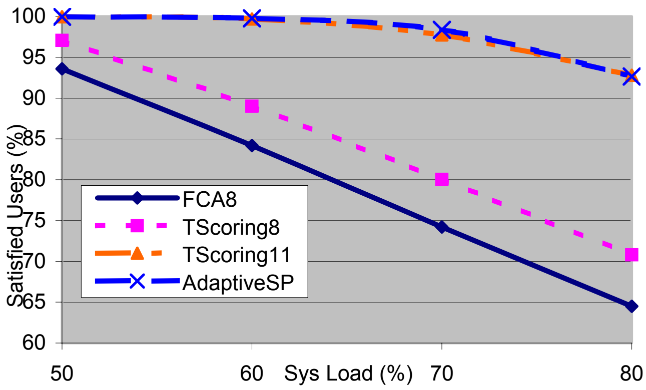

Figure 4 : Overall Satisfied User Percentage

AdaptiveSP provides the similar SUC as TScoring11. Since TScoring11 is pre-configured with optimal switching points (i.e. timeslot configuration corresponds to the traffic ratio), the graph shows that the AdaptiveSP can determine the optimal switching point within a frame. Another reason that TScoring11 and AdaptiveSP yield similar SUC is that they both share the same core algorithm. TScoring11 represents the best-case scenario when the network operator knows the traffic ratio and configure the switching point accordingly. In that case, TScoring behaves no different from AdaptiveSP. But if the operator does not know the traffic behaviour in advance or the traffic fluctuates in time, the SUC will suffer as can be seen in TScoring8. In TScoring8 and FCA8, the SUC degrades linearly and rapidly as more load is applied to the system. This indicates the lack of RU in downlink to support extra traffic. However TScoring8 still uses interference and other information to make intelligent allocation decisions and therefore is able to outperform FCA8.

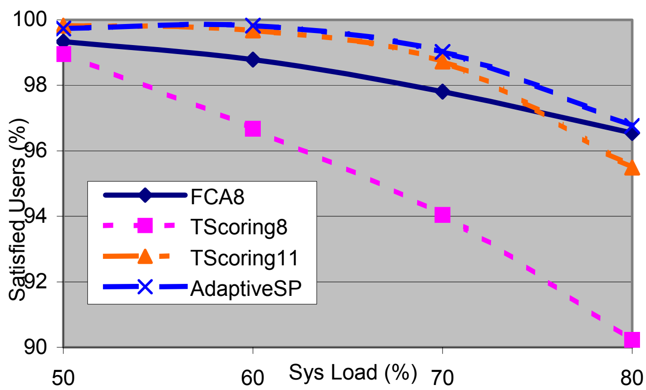

Figure 5 : Percentage of Satisfied Speech Users

Figure 5 shows the percentage of satisfied speech users in the system at different load level. TScoring8 turns out to be inferior to FCA8. This is because TScoring8 allocates more resources to packet connections and therefore less resource can be found for the speech connection. This results in higher amount of satisfied packet users (as can be seen in figure 6), but less satisfied speech users. TScoring11 and

AdaptiveSP however has more downlink resources for speech calls. Therefore, the speech users are not affected.

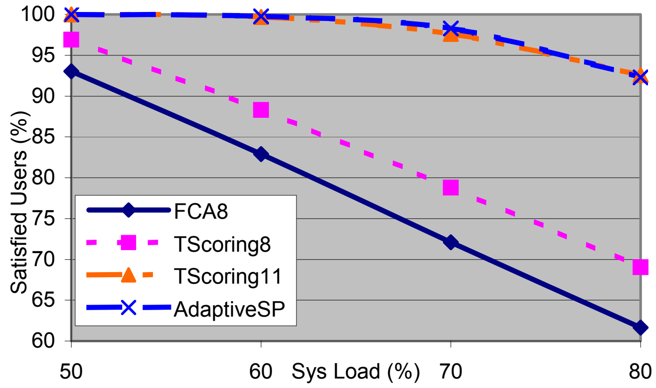

Figure 6 : Percentage of Satisfied Packet Users

Figure 6 shows the satisfied packet user percentage. The graph very much resembles the overall satisfied user percentage graph (figure 4). That is because the majority of users in the system are packet users, and therefore the overall system performance is dictated primarily by the packet service's SUC. (Although the speech and packet traffic in the system are equal in terms of overall required RU per frame, it takes much more packet users to generate the same amount of traffic as speech user.)

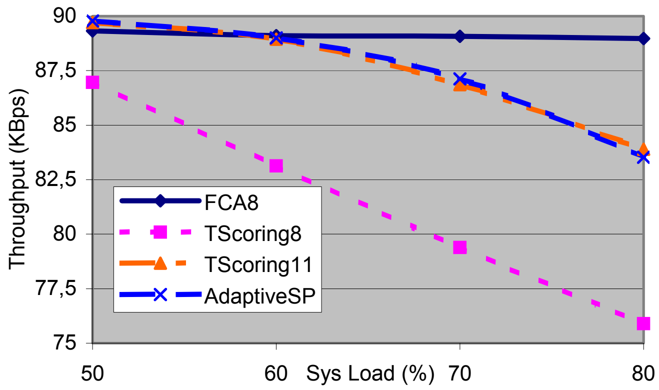

Figure 7 : Average Packet Service Throughput vs. System Load.

Another important aspect to consider is the throughput of packet calls. Figure 7 shows average throughput of packet calls at different loads. The FCA8 shows little or no degradation in average throughput. This is due to 1) FCA rejects many calls and therefore the interference in the system is kept low, 2) FCA always allocates 4 RUs for packet connection while the AdaptiveSP and TScoring do some scaling back and do not allocate maximum number of RU required every time. By scaling back on resource allocation, AdaptiveSP and TScoring can support more users but at the cost of slightly lower throughput. In this graph, AdaptiveSP and TScoring11 again yield similar performance.

Figure 8 and 9 show the cumulative throughput distribution when the system is loaded with 50% and 80% traffic. Such graph is helpful for determining the percentage of packet calls that get lower throughput than the minimum required. In figure 8 and 9, most of the users in the FCA8 system experience similar throughput close to the optimal throughput. In figure 8 where the system load is only 50%, most allocation algorithms yield similar throughput distribution. In Figure 9, the load has been increased to 80% and interference situation is more severe and diverse. The users in the system with TScoring8 will experience most varying throughput because it scales back when allocating RU. But AdaptiveSP and TScoring11 are able to improve upon TScoring8 due to more RU are available.

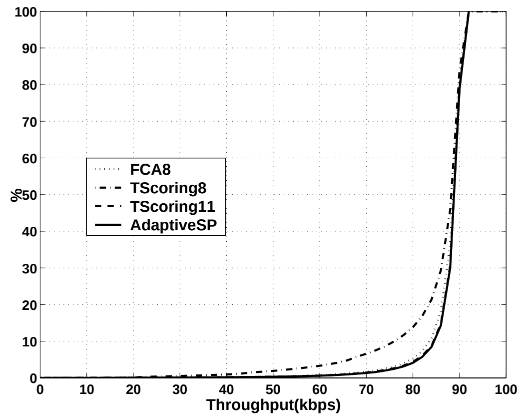

Figure 8: Downlink Throughput Distribution of Packet Service (Load 50%)

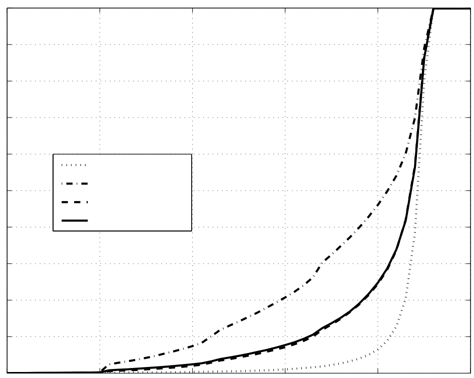

Figure 9: Downlink Throughput Distribution of Packet Service (Load 80%)

B. Hotspot Traffic Scenario

In this scenario, some BS are loaded with more traffic than the others. The hotspots are BS 1, 3, 7, and 9 (see figure 3). The traffic mixture is depicted in figure 10. The hotspot BS are loaded with 80% traffic: 40% in the form of speech service and the rest 40% in the form of packet service. Since a speech call requires 1 RU in uplink and 1 RU in downlink, this means the 40% speech traffic is split into 2 equal halves: 20% in uplink and 20% in downlink. Since a packet call is modelled as downlink only, the entire 40% is in downlink. This mixture results in overall 60% downlink and 20% uplink traffic (i.e. 3:1). The Non-hotspot BS are loaded with 50% traffic: 40% still comes from speech and the remaining 10% from packet. The downlink-to-uplink traffic ratio is therefore 3:2. This traffic mixture assumes that the UMTS network will be used primarily by packet services in the future, especially in the hotspot area. Therefore the extra UMTS traffic in the hotspot area will consist of packet service.

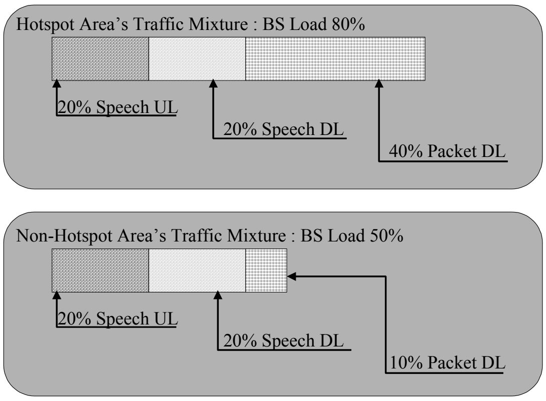

Figure 10 : Traffic Mixture in Hotspot Scenario

Again, three algorithms are simulated and the result is shown in the table 1. The FCA8 series is the result of the system using fixed switching point allocation. Each BS is pre-configured with 8 downlink slots and 7 uplink slots. TScoring8 uses TScoring algorithm. Every BS is again pre-configured with 8 downlink slots and 7 uplink slots. In TScoringMix, the switching point are pre-configured according to the traffic in each area. In the hotspot area (where the downlink-to-uplink traffic ratio is 3-to-1), the BS switching point configuration is 11-to-4. (The theoretical configuration would be 11.25-to-3.75. But this configuration is not possible since a timeslot can only be either uplink or downlink.) In the non-hotspot area (downlink-to-uplink traffic = 3-to-2), the BS switching point configuration is 9-to-6. In the system with AdaptiveSP, switching points are determined dynamically during the simulation. The satisfied user percentage evaluation in this scenario is done separately for Hotspot BS and NonHotspot BS and for each service.

TABLE 1

Overall Satisfied User Percentage (Speech and Packet)				
	FCA8	Tscoring8	TscoringMix	AdaptiveSP
Hotspot BS	75.9	82.2	98.0	97.6
NonHotspot BS	97.3	98.6	99.8	99.9
Packet Service Satisfied User Percentage				
	FCA8	Tscoring8	TscoringMix	AdaptiveSP
Hotspot BS	73.7	80.9	98.0	97.5
NonHotspot BS	96.60	98.4	99.9	99.9
Speech Service Satisfied User Percentage				
	FCA8	Tscoring8	TscoringMix	AdaptiveSP
Hotspot BS	97.7	93.9	97.2	98.7
NonHotspot BS	99.6	99.4	99.7	99.8

From the table, when FCA8 is used, the satisfied user percentage in the hotspot areas really suffers, while the Non-hotspot BS are able to maintain relatively good satisfied percentage. By looking closer, it can be seen that the extra downlink packet calls causes the problem, not the speech calls. (This is expected because the extra hotspot traffic comes from packet service.) The problem is that packet calls in the hotspot areas are blocked or cannot reconnect once they wake up from idle period, again due to the lack of RU in downlink. In the hotspot area, more packet connections are satisfied when TScoring8 is used instead of FCA8 because of the RU scaling-back and intelligent allocations. But the improvement is only marginal and the satisfied user percentage of speech service is reduced as well. This is because the problem of lacking of RU remains unsolved and resources have to be taken away from speech connections to service packet connections. The major improvement comes when AdaptiveSP or TScoringMix is applied since more resources are available in downlink.

V. Conclusion

The paper presents an adaptive switching point allocation algorithm for UTRA-TDD. The result shows overall increase in the number of satisfied users. The system's satisfied user percentage primarily suffers from the blocking of calls (both speech and packet services) or aborted packet calls. This is due to the extra traffic in one direction and the system's inability to adapt itself to the traffic and find more resources. Adaptive switching point algorithm can solve this problem. With the additional help of power control, UTRA-TDD transmission mode can offer flexible capacity from the proposed adaptive switching point algorithm. The presented adaptive switching point algorithm is suitable for real world situation where the traffic ratio cannot be easily predicted in advance or the traffic fluctuates depending on the time of the day. By employing such algorithm, a network operator can be sure that the bandwidth is utilized efficiently at all times.

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