Dynamic Channel Allocation in TDD-CDMA Systems

by Litifa Noor and Alagan Anpalagan
Ryerson University, Toronto, ON

Abstract

Mobile communication systems are increasingly required to accommodate symmetric voice traffic as well as asymmetric data traffic. This paper examines the utilization of frequency band in Time Division Duplex (TDD) mode. Since TDD mode offers the flexibility to support asymmetric channel allocation, it is identified as the preferred access methodology for multimedia traffic, which requires asymmetric channels. We also discuss channel assignment strategies such as Fixed Channel Allocation (FCA), Dynamic Channel Allocation (DCA), and Dynamic Channel Allocation with Adaptive Switching Point (DCA-ASP) that are utilized to fully access the capacity of TDD systems. DCA-ASP provides an efficient allocation of the available resources by shifting the switching point within a transmission frame to accommodate the varying traffic in each direction. Thus, DCA-ASP is a better access methodology compared to FCA and DCA in TDD-CDMA system.

Sommaire

Les systèmes de communication mobile sont de plus en plus utiles pour le traitement du trafic vocal symétrique et asymétrique. Cet article examine l'utilisation de la bande de fréquence dans le mode TDD (Time Division Duplex). Comme le mode TDD peut supporter l'allocation asymétrique de canaux, il est la méthode d'accès privilegiée pour le trafic multimédia. L'article discute des stratégies d'assignation des canaux comme le FCA (Fixed Channel Allocation), le DCA (Dynamic Channel Allocation), et le DCA-ASP (Dynamic Channel Allocation with Adaptive Switching Point). Ces derniers permettent d'exploiter au maximum les capacités des systèmes TDD. Le DCA-ASP permet une allocation efficace des ressources disponibles grâce au déplacement du point d'interrupteur se trouvant dans un paquet de transmission, s'adaptant ainsi à la variation du trafic dans chaque direction. Par conséquent, DCA-ASP est une méthode d'accès supérieure à FCA et à DCA pour les systèmes TDD-CDMA.

1.0 Introduction

The Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access (UTRA) can operate in two complementary air interface modes: FDD and TDD. Wideband-Code Division Multiple Access (W-CDMA) utilizes FDD, which is designed to support higher mobility and continuous coverage in large cells. FDD is a duplex method where paired frequency bands of symmetric width are assigned to uplink (UL) and downlink (DL) respectively. Alternatively, Time Division-Code Division Multiple Access (TD-CDMA) uses TDD, which is designed to deliver wideband traffic with high degree of asymmetry to low mobile users. TDD is a duplex method where the UL and DL transmissions are carried over the same radio frequency through utilization of synchronized timeslots. Figure 1 shows the utilization of frequency band by both the FDD and TDD modes.

As the mobile domain extends, the target of 3rd Generation (3G) mobile telecommunication systems is to provide a wide range of services, which supports multimedia traffic as well as traditional voice communication. While existing systems have been designed mainly for speech, UMTS is also intended to support wireless multimedia communication such as video and Internet. The nature of the multimedia traffic is different from speech in terms of its appearance in short bursts with high peak data rates and long idle times between consecutive requests. For a network that supports voice and data transmission, Quality of Service (QoS) requirements with respect to transmission error, throughput and delay must be considered. In contrast to voice services, multimedia traffic is highly asymmetric between UL and DL.

Due to the asymmetric traffic characteristics, the utilized communication system must support flexible UL and DL capacity without affecting the overall bandwidth efficiency. The proposed 3G systems support symmetric and asymmetric services where the channel conditions differ depending on the users' locations. Asymmetric channels in FDD systems require assignment of adjustable bandwidths for the forward and reverse links, independent filters, and different data rates, which are practically complex and costly. Alternatively, asymmetric channels in TDD system can be established through software control where the overall capacity of the TDD system is constant, but the UL and DL capacities are adjusted accordingly.

The asymmetric channel allocation makes TDD very attractive for multimedia applications, which require asymmetric channels. The ability to handle asymmetric data and reciprocal nature of TDD channels contribute to the main advantages of using TDD for mobile radio communication. In contrast, synchronization dilemmas and interference problems are considered the limiting factors of TDD systems.

2.0 Physical Channel in UTRA-TDD

The UTRA physical channel consists of TDD frames with duration of 10 ms. Each frame is divided into 15 timeslots that are assigned for either UL or DL transmission. In addition, each timeslot allows for a simultaneous transmission of up to 16 bursts by utilizing distinct spreading codes. The size of the data burst has significant impact on the performance of the network. Large data bursts lead to transmission of redundant data when enough data is not available. Alternatively, small bursts accompany large overhead for physical layer control data.

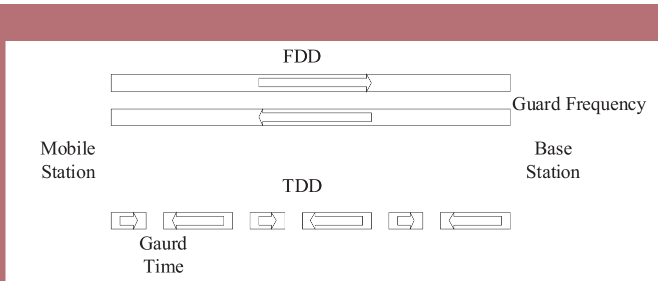

Figure 1: Utilization of Frequency Band by FDD and TDD

The combination of a specific code and a certain timeslot, in each frequency band, is referred to as Resource Unit (RU). Accordingly, 240 RUs are available in each Base Station (BS) on a single frequency. TDD physical channel has a bandwidth of 5 MHz and is located between the frequency range of 2000 MHz and 2005 MHz. Figure 2 indicates the structure of the physical channel within one TDD time frame.

TDD operation mode of UMTS allows highly dynamic and distinct configuration of the physical layer time frame. In addition, UMTS is capable of assigning different physical channel configuration to each connection in order to allow for distinct transmission bit rates with different spreading factors and error connection scheme for several types of services.

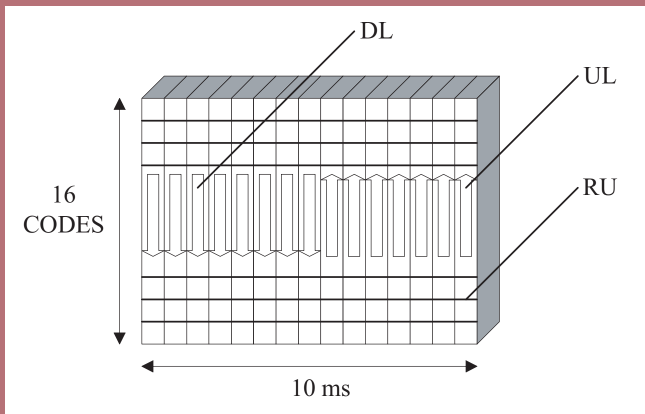

Figure 2: TDD Time Frame

3.0 Channel Assignment Strategies

In contrast to FDD, which utilizes paired frequency bands of symmetric width for DL and UL, TDD is designed to support asymmetric bandwidth allocation. A TDD system provides flexible UL and DL capacity in order to accommodate varying asymmetric traffic in both directions. A switching point indicates the location(s) within a frame where the direction of transmission changes from UL to DL and vice versa. In a TDD system, a timeslot can be utilized for UL or DL transmission in accordance to the traffic ratio. Thus, TDD mode is designed to support optimal management of the available radio resources, which is the fundamental issue in developing access methodologies. Channel assignment strategies that are utilized to access the capacity of the system can be generally categorized as Fixed Channel Allocation (FCA) and Dynamic Channel Allocation (DCA).

3.1 Fixed Channel Allocation (FCA)

In FCA, the number of allocated UL and DL timeslots specifies UL and DL capacities during initialization of the system. Thus, channels are randomly assigned to each connection and switching point movement is not supported during the system operation. Following randomization, if the selected slot is not available, subsequent slots are searched until a free slot is located. Consequently, a new call is blocked when the network fails to locate resources within the available RUs of the TDD frame. Although it can be assumed that interference is spread uniformly over the entire frame and all connections experience similar transmission quality, FCA is not capable of evaluating and adapting to the current connection quality. Thus, FCA cannot support optimal management of the available radio resources.

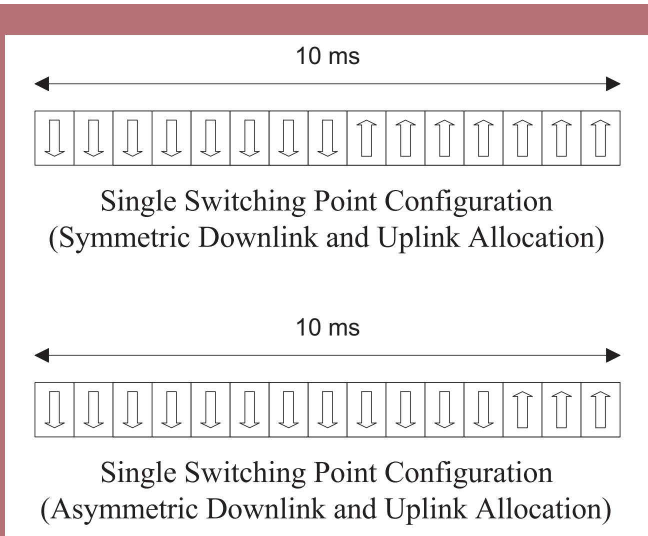

Figure 3: DCA in TDD Frames

3.2 Dynamic Channel Allocation (DCA)

DCA allows the system to utilize the radio resources more efficiently compared to FCA. DCA schemes allow rearrangement of the allocated resources in order to improve connection quality. Thus, QoS is ensured by DCA through assignment of appropriate number of resources. Like FCA, DCA does not support the movement of the switching point. Hence, the number of UL and DL slots is fixed and the switching point is not shifted during transmission. Figure 3 indicates DCA in TDD frames.

Based on channel measurement, DCA schemes assign RUs to the connection, which will likely offer the best available transmission. A simple interference based DCA scheme assigns the Least Interfered Resource (LIR) in DL and UL to the connections. In order to determine that a certain timeslot provides an adequate quality, it specifies a predefined interference threshold for the UL and DL connections. Thus, connections are blocked depending on the interference threshold. The blocking probability of the connections increases with a decrease in the threshold value. Interference based DCA has advantages over FCA in terms of Bit Error Rate (BER) performance. Since DCA reallocates resources with low transmission quality, it offers improved QoS with respect to satisfied subscribers.

4.0 An Interference Based DCA Algorithm

The following algorithm describes an interference based DCA in TDD mode [1].

1. An interference threshold is predefined for speech as well as packet service types. The threshold defines the maximum value below which data or voice is transmitted and received without distortion. In addition, the optimal number of RUs required per frame, for each UL and DL, is parameterized for different services. The parameter enables the system operator to provide distinct packet data services depending on the transmission speed.
2. During initiation of a connection, the mobile terminal measures the signal quality of the local base station. Following, a connection request is transmitted to the BS with the best signal quality. Subsequently, DCA acquires the interference data for each timeslot. For DL the interference is measured at the mobile terminal, while for UL the interference is measured at the base station.
3. DCA compares the interference data with the threshold value. Subsequently, +4 points are assigned to any timeslot with a lower interference level compared to the threshold. Alternatively, -1 point is assigned to the timeslots, which are not considered for the connection.
4. Then, DCA compares the available RUs in the frame with the number required by the service type. An additional 4 points are given to each slot that has the required number of RUs.
5. If the slot contains RUs for only 50 percent of the required capacity, +2 points are assigned. Also, +1 point is given to each timeslot, which is capable of supporting a connection with at least one RU.
6. Finally, the timeslot with the highest score is selected. If both UL and DL allocations are required, DCA must find RUs in both directions.

According to the above algorithm, Step 3 checks the interference level of the timeslot while Steps 4 -6 determine the availability of RUs for the requested service type. DCA makes use of interference limits and RUs requirement parameters of the services in order to allocate radio recourses. By adjusting the interference limit parameters, the system operator can influence the number of blocked calls. RUs requirement parameters enable the system operator to vary the throughput of packet data service. Finally, depending on channel measurements, DCA schemes attempt to assign RUs to the connection, which offers comparatively better transmission quality. Thus, DCA provides enhanced quality of service through appropriate allocation of radio resources.

Furthermore, DCA offers the possibility to allocate resources based on the current connection quality as an additional feature. For speech services, this quality criterion can be the BER of the connection. In the case where the BER is higher than a predefined value, the connection is blocked and a reallocation request is generated and executed. In order to avoid system instabilities, reallocation is permitted after a specific period of steady RU allocation. This is to consider possible failed reallocation attempts when the BER stays above the threshold and limits the dynamic of reallocation.

5.0 DCA with Adaptive Switching Point Strategy (DCA-ASP)

DCA-ASP strategy provides an efficient allocation of the available resources to multimedia traffic. Adaptive Switching Point (ASP) is designed to dynamically adjust the bandwidth to suit the traffic ratio by assigning different number of timeslots for UL and DL. Consequently, the adaptation results in higher throughput. DCA-ASP supports asymmetric services and carries UL and DL allocations with multiple switching points. By placing the switching point within a transmission frame dynamically, a TDD system can provide flexible UL and DL capacity to accommodate varying asymmetric traffic in each direction. Figure 4 indicates multiple switch point configurations in a TDD frame.

The disadvantages associated with the Adaptive Switching Point allocation are comparatively complex resource allocation schemes, and cross mobile interference for overlapping timeslots that are utilized differently in neighboring cells. The interference instances occur due to overlapping timeslot (TS) when, for example, BS1 utilizes TS3 for DL while BS2 uses TS3 for UL as illustrated in Figure 5.

In accordance with the above scenario MS1 is receiving data in TS3. Since MS2 is transmitting on the same slot, MS1 receives interference from MS2, which is referred to as MS-MS interference. In addition, BS2 receives signals from MS2 and interference from BS1, which is transmitting on TS3 in the DL direction. This is referred to as BS-BS interference. The MS-MS and BS-BS interferences that are generated by asymmetric switching point can become a major limiting factor of the TDD mode. In order to eliminate the interference instances, a TDD system requires an effective channel allocation algorithm, which can coordinate TS assignment between base stations in a cellular network. Although the switching point allows an efficient allocation of resources, losses in capacity may occur when time slots in neighbored cells are allocated differently. The loss in capacity results from the interference that takes place between the UL and DL traffic in the corresponding timeslots.

ASP strategy shares the same algorithm as DCA with an additional feature that supports movement of the switching point. ASP follows the steps defined in the DCA. However, if a connection is blocked in Step 3 of the DCA algorithm that was discussed above, the timeslot at the border between the UL and DL is freed up for the connection. Suppose

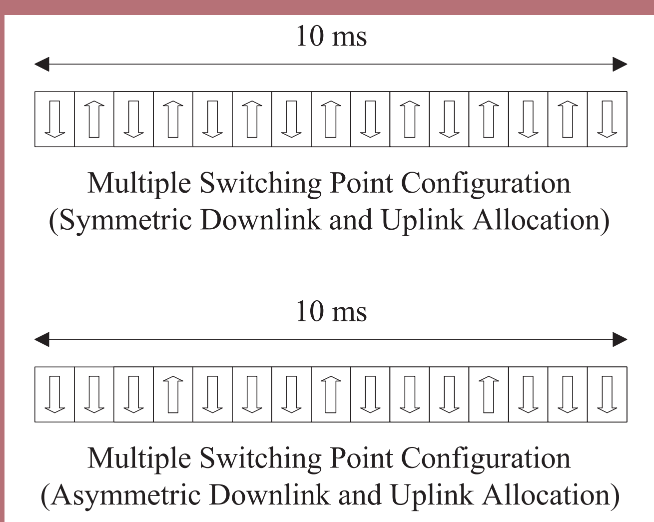

Figure 4: Multiple Switching Point Configuration in a TDD

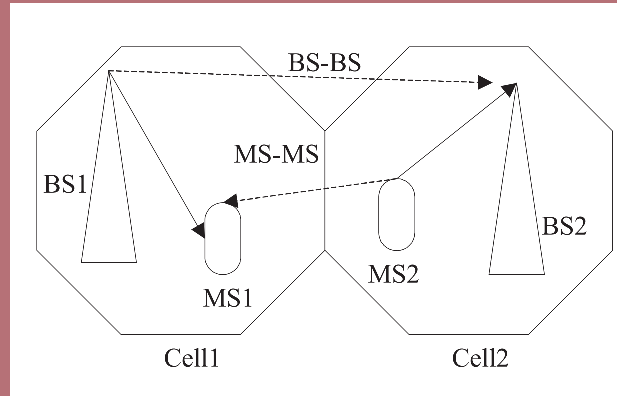

Figure 5: Interference Instance in Overlapping Timeslot (TS3)

TS0-TS9 are utilized by DL and TS10-TS14 are employed by UL as indicated in Figure 6.

Upon the request of a new DL connection, the following five steps are executed [7]:

1. Adaptive switching point utilizes DCA algorithm to allocate resource in DL for the connection. However, the connection is blocked in Step 3 due to high interference in the DL timeslots. Consequently, the slots are marked as unusable.
2. Adaptive switching point attempts to increase the DL capacity by freeing up TS10, which is the subsequent UL timeslot.
3. The connections in TS10, which has been freed up for DL transmission, are reassigned to the next available UL timeslots.
4. If adaptive switching point allocates a suitable UL slot for the existing UL connections, TS10 is utilized for DL and the switching point is relocated.
5. Alternatively, if the adaptive switching point fails to allocate a suitable UL slot for the existing UL connections, the new DL connection is blocked.

Thus, DCA with Adaptive Switching Point increases the total number of satisfied users.

6.0 Conclusion

TDD mode is well suited for multimedia traffic with asymmetric characteristics. With the dominance of unbalanced traffic, optimal management of the available radio resources has become the primary concern in developing radio access methodologies. Channel assignment strategies that are utilized to access system's capacity in TDD are primarily based on FCA and DCA principles. DCA allows the system to utilize the radio resources more efficiently compared to FCA. Dynamic allocation is based on the criteria that offer instantaneous quality of service to the connections. In addition, it allows rearrangement of the allocated resources to increase connection quality in case of a possible impending connection breakdown. DCA-ASP provides an efficient allocation of the available resources by dynamically placing the switching point within a transmission frame to accommodate the varying traffic in each direction. Hence, DCA-ASP is a better access methodology compared to DCA in TDD-CDMA systems.

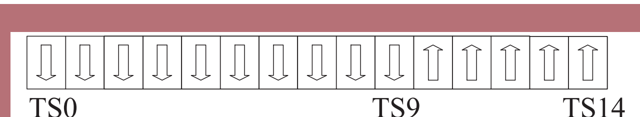

Figure 6: Adaptive Switching Point

7.0 References

[1]. T. Kriengchaiyapruk and I. Forkel, "Dynamic Allocation of Capacity in UTRA TDD Systems," 3G Mobile Communication Technologies: Second International Conference, pp. 262-266, March 2001.

[2]. D. Jeong and W. Jeon, "CDMA/TDD System for Mobile Multimedia Communications", IEEE International Conference, vol. 2, pp. 994-998, June 1998.

[3]. D. Jeong and W. Jeon, "CDMA/TDD System for Wireless Multimedia Services with Traffic Unbalance between Uplink and Downlink", IEEE Journal of Selected Areas in Communications, vol. 17, pp. 939-946, May 1999.

[4]. M. Haardt, A. Klein, R. Koehn, S. Oestreich, M. Purat and V. Sommer, "The TD-CDMA based UTRA TDD Mode", IEEE Journal of Selected Areas in Communications, vol. 18, pp. 1375-1385, August 2000.

[5]. L. Chen, U. Yoshida, H. Murata and S. Hirose, "Dynamic Timeslot Allocation Algorithms Suitable for Asymmetric Traffic in Multimedia TDMA/TDD Cellular Radio", IEEE Vehicular Technology Conference, vol.2, pp. 1424-1428, May 1998.

[6]. H. Haas and S. McLaughlin, "A Novel Channel Assignment Approach in TDMA/CDMA-TDD Systems", Personal, Indoor and Mobile Radio Communications, 12th IEEE International Symposium, vol. 2, pp. 142-146, Fall 2001.

[7]. T. Kriengchaiyapruk and I. Forkel, "Adaptive Switching Point Allocation in TD/CDMA Systems", IEEE Vehicular Technology Conference, vol.3, pp. 1456-1460, September 2002.

[8]. H. Yomo, A. Nakata and S. Hara, "An Efficient Slot Allocation Algorithm to Accommodate Multimedia Traffic in CDMA/TDD-based Wireless Communications Systems", IEEE Vehicular Technology Conference, vol.2, pp. 787-791, October 2001.

[9]. J. Zhang and W. Wang, "A Dynamic Channel Allocation Algorithm in TDD Mode CDMA Systems", IEEE Vehicular Technology Conference, vol. 1, pp. 385-388, Fall 2001.

[10]. 3GPP RAN TS 25.202 v3.4.0 (1999-9) Technical Specification Group Radio Access Network: Physical Layer General Description (TDD), www.3GPP.org

8.0 Acronyms

ASP:	Adaptive Switching Point
BS:	Base Station
BER:	Bit Error Rate
DL:	Downlink
DCA:	Dynamic Channel Allocation
FCA:	Fixed Channel Allocation
FDD:	Frequency Division Duplex
LIR:	Least Interfered Resource
MS:	Mobile Station
QoS:	Quality of Service
RU:	Resource Unit
TD-CDMA:	Time Division-CDMA
TDD:	Time Division Duplex
TS:	Timeslot
UL:	Uplink
UMTS:	Universal Mobile Telecommunication Systems
UTRA:	UMTS Terrestrial Radio Access
W-CDMA:	Wideband CDMA
3G:	3rd Generation

About the authors

Litifa Noor is a 4th year Electrical Engineering student at Ryerson University. Her current research interests include analysis of different channel allocation strategies in TDD-CDMA, synchronization techniques for wideband TDD-CDMA, and digital signal processing for communications. She is the Chair of the IEEE Student Branch at Ryerson University in 2003-2004, and the Organizing Chair of the International Conference for upcoming Engineers, which was held at Ryerson University in May 2004.

Alagan S. Anpalagan is an Assistant Professor at Ryerson University where he co-founded WINCORE laboratory and directs the WAN (Wireless Access and Networking) R&D group. His research interests are in QoS-aware radio resource management; joint study of wireless physical and link layer characteristics; and cellular/multihop radio communication for 4G systems. He has published more than 30 papers and articles in international conferences and journals in his research area. He currently serves as Technical Program Co-Chair, IEEE CCECE'04; Chair, Communications Chapter - IEEE Toronto Section; and Counselor - IEEE Ryerson. He holds a Ph.D. in Electrical Engineering from University of Toronto.

Outstanding student paper awards at the CCECE'2004 Conference in Niagara Falls, May 2004

Four prize winning papers submitted by students were selected at the Conference. Unfortunately, only two students were present to pick up their awards at the Luncheon held on Tuesday 4 May, 2004. The four papers were:

1. A Differential Space-Time Code Receiver using the EM-Algorithm, M. L. B. Riediger, Simon Fraser University,
2. 2-D CMOS based Image Sensor System for Fluorescent Detection, Yasaman Ardeshirpour, McMaster University,
3. Receive Antenna Selection for Space-Time Block Codes, Xiang Nian Zeng, Concordia University,
4. Implementing Task Scheduling and Event Handling in RTOS+, Cyprian F. Ngolah, University of Calgary.

Bill Kennedy (left), President of IEEE Canada presents the award to **M. L. B. Riediger** (center) from Simon Fraser University while Janet Bradley (right) reads the citation. The awards consisted of a plaque and a book generously donated by Alex Greene of Kluwer Academic Publishers, Boston.

Bill Kennedy (center), President of IEEE Canada presents the award to **Cyprian F. Ngolah** (left) from University of Calgary while Janet Bradley (right) reads the citation. The awards consisted of a plaque and a book generously donated by Alex Greene of Kluwer Academic Publishers, Boston.