TD-SCDMA Physical Layer Design Overview

Author Information
College: Information Security Engineering College
Class: F0503602
Name: SHI Junxiao
Instructor: WU Yue
Instructor's college: Information Security Engineering College

ABSTRACT

TD-SCDMA is the first 3G mobile network launched in China. This paper takes a look at the specification of TD-SCDMA, and focuses at the physical layer design.

KEYWORDS TD-SCDMA, 3G, mobile, physical layer

1 Overview

1.1 Current Status

Time Division-Synchronous Code Division Multiple Access, or TD-SCDMA, is a 3G mobile telecommunication standard, being persued in the People's Republic of China, in an attempt not to be "dependant on Western technology". "Commercial trials" across eight cities was launched on April 1, 2008 and will eventually include 60,000 users.

As I read in cnBeta.com, the results were unsatisfactory. Many users reported that the signal is not as good as the 2G networks, GSM or CDMA. There are only a small number of TD-SCDMA users, so users don't know who they can make Video-Call to. More Internet cards were sold than cell phones.

1.2 Value of my Topic

TD-SCDMA standard has been adopted by 3GPP since Rel-4, and offered as air interfaces for the UMTS-TDD system.

It's interesting and useful to know something deep of this blooming 3G network.

1.3 Purpose and Scope

I am writing this paper to share my findings when I'm reading a part of TD-SCDMA Technical Specification.

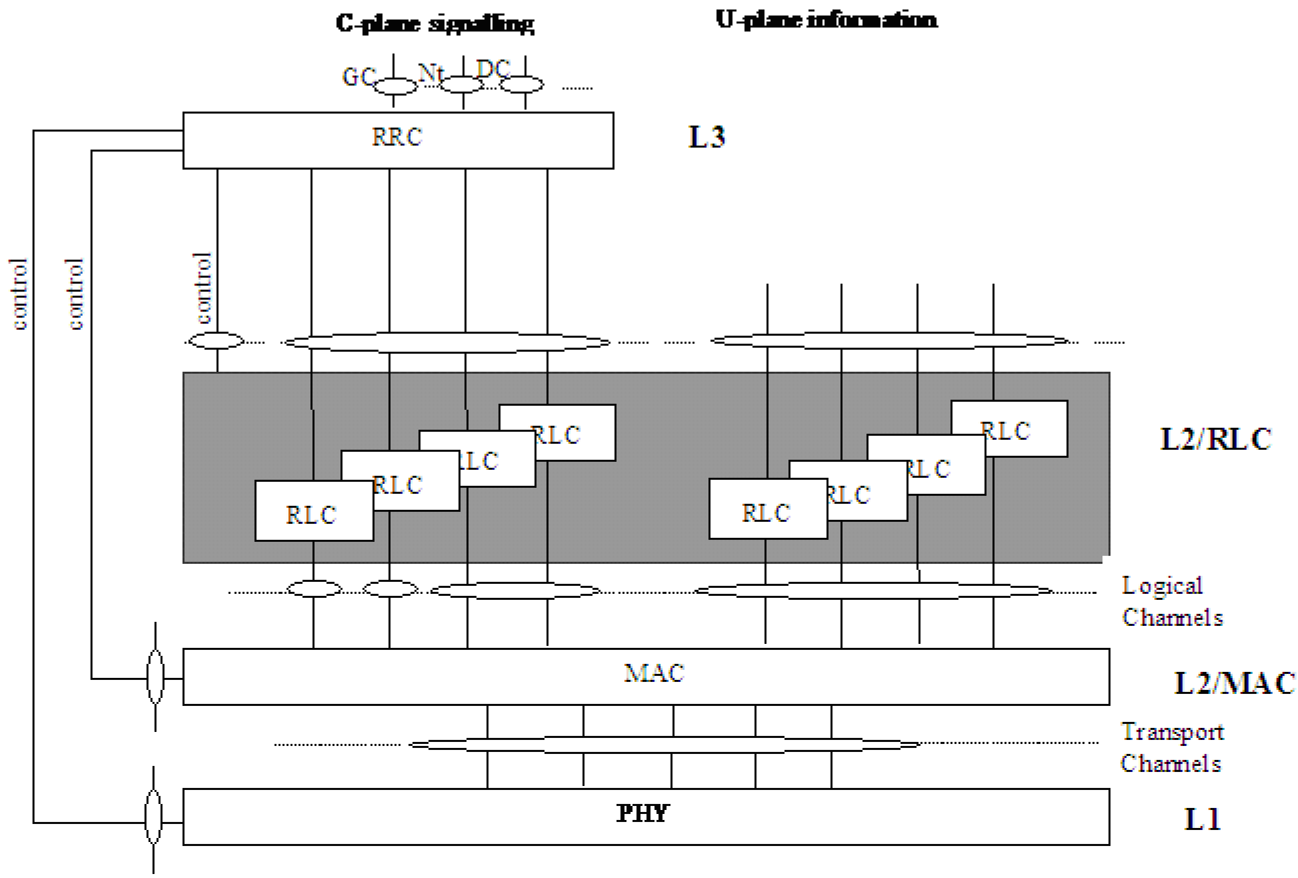
I will focus on the overall architecture and the physical layer, only a little of other parts will be mentioned. I will try to find out *why* they design the physical layer like that.

2 Radio Interface Protocol Architecture

TD-SCDMA is assumed to use an architecture of User Equipment (UE), RAN, and Core Network. Radio interface acts as the Access Stratum of TD-SCDMA.

The radio interface is divided into three protocol layers:

- L3, network layer (RRC)
- L2, data link layer
  - RLC, Radio Link Control sublayer
  - MAC, Medium Access Control sublayer
- L1, physical layer



It's obvious that these three layers are taken from the famous OSI 7-layer model. Define the protocol in each layer, define the interface on each SAP, then a change in any layer won't affect other layers.

The future of communication is All-IP (everything will be packed in IPv6 packets). As a 3G standard, using the OSI 7-layer model is appropriate.

Radio interface protocol includes only the lowest three layers of the OSI model, because this standard defines only the access stratum. It's enough to use only those three layers to provide a QoS-aware end-to-end data transfering and necessary controling & charging functions.

2.1 Physical Layer

The physical layer offers information transfer services to MAC layer. L1 should know how to transfer those data over the radio interface.

It provides two types of transport channels:

- common transport channels: there is a need for in-band identification of the UEs, by using addresses
- dedicated transport channels: UEs are identified by the physical channel

Major functions:

- error detection, FEC encoding/decoding
- rate matching
- mapping transport channels to physical channels (code, time slot, frequency)
- power control
- synchronization control
- beamforming for uplink & downlink
- user positioning

More about the physical layer will be discussed in chapter 3.

2.2 MAC Layer

The MAC sublayer provides:

- unacknowledged data transfer: send SDUs to another MAC entity. But no ACK is provided, so there is no guaranteeing. This service does not provide any data segmentation, either.
- reallocation of radio resources and MAC parameters
- reporting of measurements: This can be used for charging.

Major MAC functions:

- mapping logical channels to transport channels
- selection of "Transport Format" or "Transport Format Set" depending on instantaneous source rate.
  This is one of the technical highlights in TD-SCDMA: supporting dynamic bit-rate, and even different downlink / uplink rates.
- priority handling between data flows of one UE, or between UEs
- identification of UEs on common transport channels

This MAC sublayer is similar to the one in TCP/IP. Unlike the wired computer network, its bit-rate is changing instantaneously, and it should use precious transport resources efficiently.

2.3 RLC Layer

The RLC sublayer provides:

- RLC connection
- data transfer
  - transparent data transfer: without adding RLC header
  - unacknowledged data transfer: no guaranteeing, out-of-sequence; assures error-free, unique, immediate
  - acknowledged data transfer: guaranteeing (maybe by ARQ); assures error-free, unique; can be in-sequence or out-of-sequence
- QoS setting

It seems that RLC can provide some services like UDP and TCP, but this is in the data link layer! I'll explain this later.

Major RLC functions:

- connection control
- segmentation, compression, concatenation, padding
- transfer of user data, error correction, in-sequence delivery, duplicate detection
- flow control

2.4 RRC Layer

The RRC layer provides:

- general control
- notification
- dedicated control

RRC is focusing on "control". In fact, RRC & RLC are divided into Control-plane and User-plane.

2.5 Why is "UDP & TCP" appearing in RLC?

As I mentioned above, three types of data transfer services is provided in the RLC sublayer. Unacknowledged data transfer looks like UDP (however UDP does not ensure unique), and acknowledged data transfer looks like TCP.

In computer network, UDP and TCP are on transport layer (layer 4). But they are here on the data link layer, why?

Let take a look at layer 2-4 in TCP/IP.

LAYER	MAJOR PROTOCOLS	MAJOR SERVICES & FUNCTIONS	TD-SCDMA equivalent
L2 data link	802.3 Ethernet,	unacknowledged	MAC sublayer

	802.11 wireless	peer-to-peer data transfer, identification of stations with MAC addresses	
L3 network	IP	routing with IP addresses	none
L4 transport	TCP UDP	unacknowledged / acknowledged end-to-end data transfer, flow control, (TCP)Automatic Repeat reQuest	RLC sublayer

Now it's clear that "UDP & TCP" are moved into the data link layer because of the absence of "IP" routing requirements. TD-SCDMA's MAC layer do have routing function, but that's the routing of signalling.

In mobile communication systems, radio interface is between Mobile Station (UE in TD-SCDMA) and Base Station, and controlling is mostly done by Mobile Switching Center rather than data stations themselves. Routing of user data is not necessary in radio interface, so "UDP & TCP" can be moved down to RLC sublayer on L2.

3 Details about the Physical Layer

3.1 Transport Channels

There are two types of transport channels: common channels, where there is a need for in-band identification; dedicated channels, where UEs are identified by physical channels.

Transport channels and mapping to physical channels: (optional channels are omitted)

PHY	PHYSICAL CHANNEL	TIME SLOT / CODE	L1	TRANSPORT CHANNEL	TYPE	UP/DOWN	CONTENT
PRACH	Physical Random Access Channel	Tu0, code 0/1/2/3	RACH	Random Access Channel	common	uplink	initial access, non-realtime

							dedicated control / traffic
CCPCH	Common Control Physical Channel	Td1/Td0, code C/D/E/F	FACH	Forward Access Channel	common	downlink	small amount of data
DPCH	Dedicated Physical Channel		DSCH	Downlink Shared Channel	common	downlink	(several UEs) dedicated control / traffic
DPCH	Dedicated Physical Channel		USCH	Uplink Shared Channel	common	uplink	(several UEs) dedicated control / traffic
CCPCH	Common Control Physical Channel	Td0, code 0/1	BCH	Boardcast Channel	common	downlink	system information (into entire cell)
PSCH	Physical Synchronization Channel		SCH	Synchronization Channel	common	downlink	synchronization information (into entire cell)
CCPCH	Common Control Physical Channel	Td0, code 0/1	PCH	Paging Channel	common	downlink	paging & notification (for UE idle

							mode procedures)
DPCH	Dedicated Physical Channel	one or more (TS,code)	DCH	Dedicated Channel	dedicated	up & down	

TD-SCDMA is designed to use two types of transport channels.

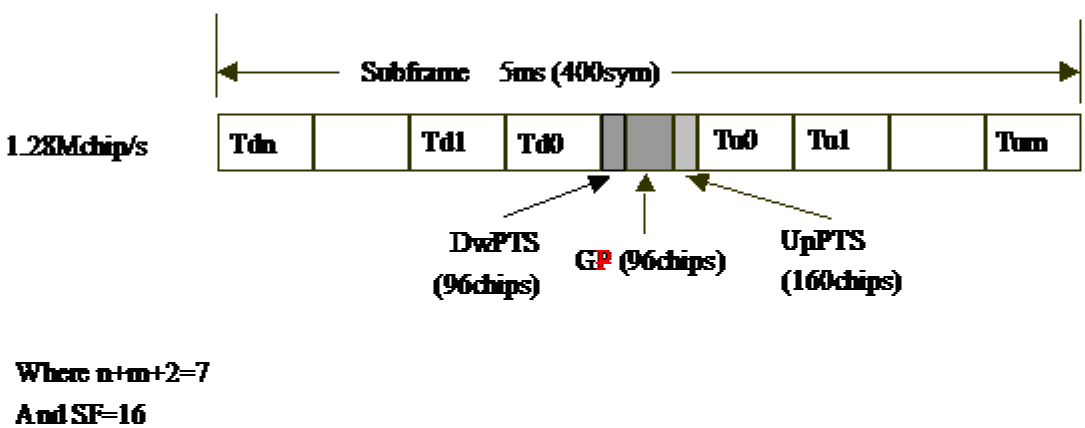
- boardcast on common channels, because they should be received by all UEs
- initial access on common channels, because there is no way for a "new" UE to know its dedicated channel
- large amount of (realtime) data (control information or user data) on dedicated channels, because doing CSMA/CD on common channels may delay the transmit and can't ensure realtime
- small amount of (non-realtime) data on common channels, because CSMA/CD won't delay this little piece so much

Mobile communication systems should be designed to save bandwidth / channels, so TD-SCDMA is designed like that.

3.2 Physical Channels

Every signal is eventually transmitted on a physical channel. Physical channels are identified by code, time slot, frequency.

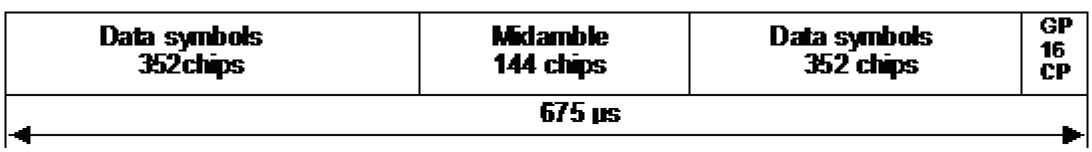
TD-SCDMA's physical channels take a four-layer structure:



- superframe, 720ms; contains 72 radio frames
- radio frame, 10ms; contains 2 subframes
- subframe, 5ms, 1.28Mchip/s; contains 7 main time slots and 3

special time slots
  - 7 main time slots can be used as downlink or uplink. 1 downlink & 6 uplink, or 1 uplink & 1 downlink are both allowed, it's not required to have down/uplinks in pair. This design make TD-SCDMA fit the need where "down rate != up rate"
  - downlink slots come first, followed by DwPTS & G & UpPTS (used for synchronization), uplink slots appear last
- time slots
  - main time slot (TS), 675μs
  - Downlink Pilot Time Slot (DwPTS), 75μs
  - Uplink Pilot Time Slot (UpPTS), 125μs
  - Guard Period (G), 75μs; indicates the switching point from downlink to uplink

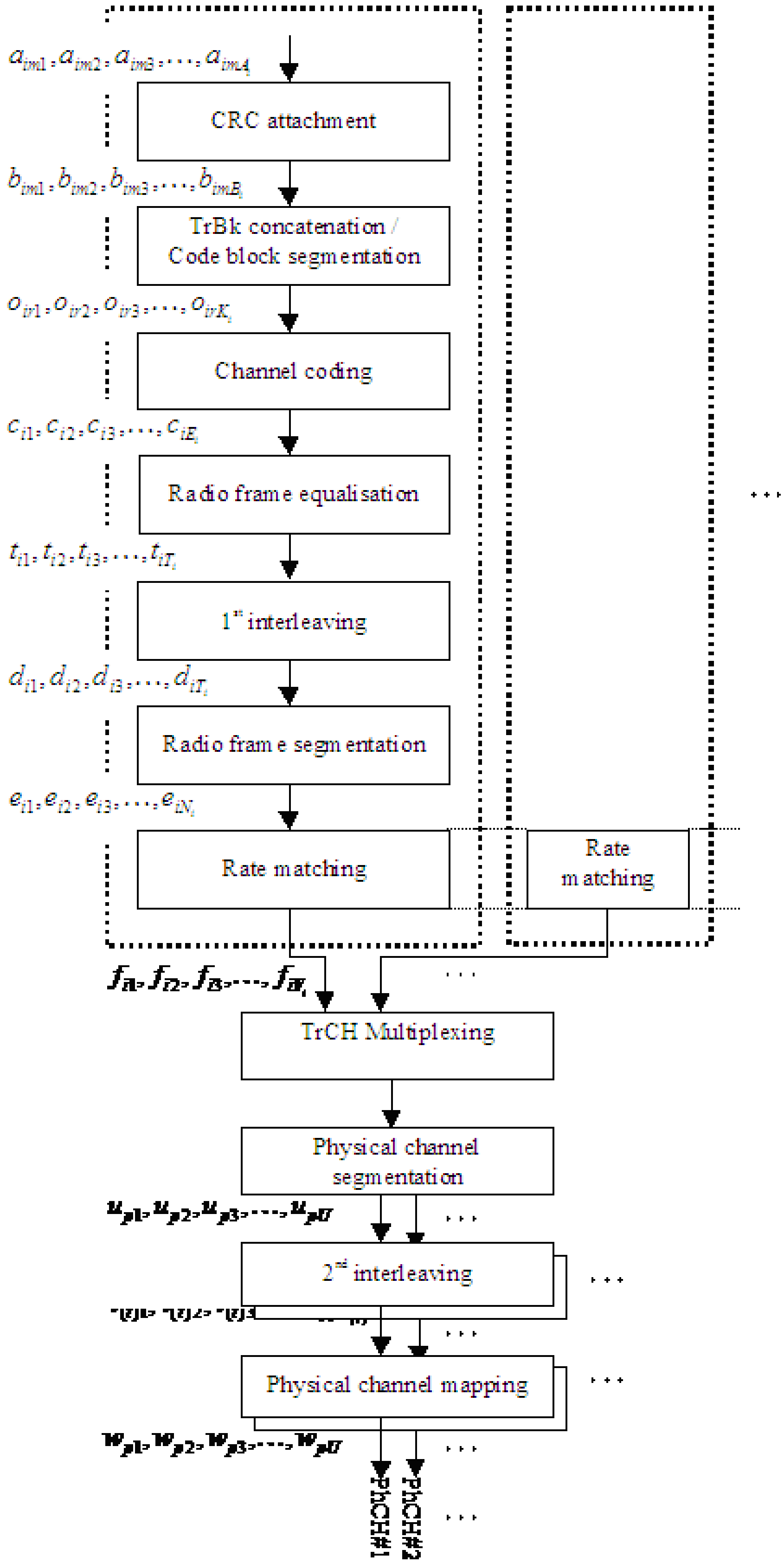
Dedicated physical channels are located in main time slots. With spreading codes, up to 16 users' bursts can be transmitted within one TS. Each burst contains 704 chips for transmitting data. If there are 16 users in this TS, these 704 chips can transmit 22 symbols(bits) of each user; if there are only 4, 88 symbols are transmitted.



"Data symbols" are used to transmit user data from the data link layer. But when there is need to transmit L1 control data (eg. CRC), the physical layer may "steal" several symbols.

3.3 Multiplexing and Channel Coding

Data stream from/to MAC is encoded/decoded to offer transport services. Channel coding scheme includes error detection, error correcting, interleaving and mapping transport channels onto physical channels (one data stream mapped onto one or several physical channels).



$a_{im1}, a_{im2}, a_{im3}, \ldots, a_{imA_i}$
CRC attachment
$b_{im1}, b_{im2}, b_{im3}, \ldots, b_{imB_i}$
TrBk concatenation / Code block segmentation
$o_{ir1}, o_{ir2}, o_{ir3}, \ldots, o_{irK_i}$
Channel coding
$c_{i1}, c_{i2}, c_{i3}, \ldots, c_{iE_i}$
Radio frame equalisation
$t_{i1}, t_{i2}, t_{i3}, \ldots, t_{iT_i}$
1st interleaving
$d_{i1}, d_{i2}, d_{i3}, \ldots, d_{iT_i}$
Radio frame segmentation
$e_{i1}, e_{i2}, e_{i3}, \ldots, e_{iN_i}$
Rate matching
Rate matching
$f_{i1}, f_{i2}, f_{i3}, \ldots, f_{iV_i}$
TrCH Multiplexing
Physical channel segmentation
$u_{p1}, u_{p2}, u_{p3}, \ldots, u_{pU}$
2nd interleaving
Physical channel mapping
$w_{p1}, w_{p2}, w_{p3}, \ldots, w_{pU}$
PhCH#1
PhCH#2

1. error detection: provided through CRC. Higher layers should tell L1 to use 24,16,8 or 0 bits of CRC
2. transport block concatenatation / segmentation
3. channel coding: convolutional code or turbo code may be applied, chosen by higher layers.
4. radio frame size equalisation: pad the input to ensure the output can be segmented in several segments of same size
5. 1st interleaving: to avoid interfere
6. radio frame segmentation
7. rate matching: bits are repeated for slow rate
8. TrCH multiplexing
9. physical channel segmentation
10. 2nd interleaving: to avoid interfere
11. physical channel mapping
12. multiplexing & mapping to CCTrCH
13. transport format detection

3.4 Spreading and Modulation

Table 1: Basic modulation parameters.

Chip rate	1.28Mcps
Carrier spacing	1.6MHz
Data modulation	QPSK or 8PSK(optional)
Chip modulation	Root-raised cosine roll-off $\alpha = 0.22$
Spreading characteristics	Orthogonal Qchips/symbol, where $Q = 2^p$, $0 <= p <= 4$

- 1G: only FDMA is used, only a very small number of users are supported.
- GSM: FDMA & TDMA are used, supports several thousand users. When there is more, "CMCC" disappears from UEs' screen.
- W-CDMA: FDMA & CDMA is used, supports "unlimited" users. When an implementation wants to support so many users, multiuser detection and beamforming schemes are too complex.
- TD-SCDMA: using a combination of FDMA, TDMA & CDMA, supports "unlimited" users. Usage of TDMA reduces the number of users in each time slot (and improves the orthogonality between the codes), so multiuser detection and beamforming become easier, but the non-continuous transmission may reduce coverage & mobility.

4 Conclusion

TD-SCDMA is one of 3G radio interface standards. Its highlights are:

- combination of FDMA, TDMA, CDMA: multiuser detection becomes simple
- TDD: downlinks & uplinks do not need to be in pair, accommodating asymmetric traffic with dynamic rates

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