Computer Communications 32 (2009) 1505–1514

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Discrete-time control analysis of transport channel synchronization in 3G radio access networks

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ARTICLE INFO

Article history:
Received 17 December 2008
Received in revised form 30 April 2009
Accepted 9 May 2009
Available online 20 May 2009

Keywords:
UTRAN
Frame protocol
Control system
Synchronization
Iub

ABSTRACT

Transport channel synchronization is a function of 3G access networks that operates in the link between Radio Network Controllers (RNCs) and Base Stations (Nodes B) and is required to support macro-diversity in the downlink direction. Its objective is to assure that every frame sent by the RNC arrives at the Node B on time to be transmitted over the air interface avoiding excessive buffering at the Node B. This is achieved by means of a timing adjustment algorithm that tracks the delay of the link and corrects the sending time of the frames in the RNC. However, when the link experiences abrupt delay variations, e.g. because of a sudden traffic increment in an intermediate node, the classic algorithm may loss frames and, depending on its configuration and the transport delay, it can show an undesired oscillatory behaviour. In this paper we analyze the response of this mechanism under sudden delay increments, providing useful guidelines to configure it in order to prevent oscillations, avoiding excessive signalling and eventual frame losses. Moreover, we propose a simple algorithm that overcomes the limitations of the classic scheme. The configuration of our proposal is addressed by means of discrete-time control theory focusing on stability and performance considerations. We show the influence of the delay on these issues and present an adaptive strategy to make the system robust under delay variations.

1. Introduction

In UMTS Terrestrial Radio Access Networks (UTRAN), link-level communication between Nodes B and Radio Network Controllers (RNCs) through the Iub interface is regulated by the Frame Protocol (FP), specified by the 3GPP in [1–3]. For dedicated channels (DCH), the Transport Channel Synchronization function of FP has the objective of delivering each frame to the Node B within a reception window which assures that the frame is transmitted over the air interface at its corresponding Transmission Time Interval (TTI) with the less possible buffering per channel at the Node B. Packet queuing should be done in the RNC, where the scheduling and the resource management processes are located.

The Iub interface is supported by an ATM or IP-based network, generally referred to as UTRAN transport network. The delay of the Iub depends on several factors, e.g. the distance of the links between the RNC and the Node B, the traffic intensity at each link, the amount of intermediate nodes, etc. This delay may experience abrupt variations in diverse situations:

- An intermediate node in the UTRAN transport network handling a large amount of traffic.
- When traffic engineering or path restoration mechanisms reroute Iub flows. See [6] and the references therein.
- If a source has been idle for a long time and the delay has experienced a noticeable drift that the synchronization process is not able to follow.

In the examples provided in [7], one-way delay of different Iub branches ranged from 12 to 31 ms considering voice traffic and ATM transport. The differences between Iub branches may be even higher for UTRAN-IP and data services, especially under heavy traffic.

Delay variations should be compensated by FP in order to assure that frames keep arriving within the reception window. This function is performed by the transport channel synchronization procedure and, more specifically, by the timing adjustment algorithm explained later in this paper. However, when delay variations are very steep, it takes some time to readjust the synchronization. During this time two facts affect the performance of the channels: (i) the signalling traffic in the Iub increases, (ii) frames arriving too far from the window boundaries are discarded, causing temporary performance degradation on the channels multiplexed over the Iub.

The duration of the degraded period after an abrupt delay variation depends on the timing adjustment algorithm implemented and on its configuration. Surprisingly, this issue has received little attention in previous research. The work in [5] is the only one, to

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doi:10.1016/j.comcom.2009.05.006

the best of our knowledge, focused on transport channel synchronization. Authors propose a modification of the classic timing adjustment algorithm (CA). However its operation under abrupt delay increment is completely analogous to CA. Other works like [8–11] focus on the relationship between timing adjustment and Iub congestion. The starting point of these works is that delay variations provide information about the congestion in the Iub interface that may be used to flow-control data channels. However, all these papers assume that 3G nodes implement CA and no improvement to this scheme is suggested. The interest on transport channel synchronization is also present in [12] where it is discussed the impact of this issue on the design of QoS schemes for UTRAN-IP. All the aforementioned references come from laboratories and research groups of equipment manufacturers, which reveals the interest of the telecommunication industry in this issue.

In this paper we make the following contributions: first, we analyze the response of CA against steep delay increments. The results of this analysis are useful to configure the window size and the correction step size to prevent oscillations. Second, we propose a simple algorithm based on correcting the offset proportionally to the distance between the TOA and the centre of the window. This proposal can be analyzed by means of discrete-time control theory, which let us use classical techniques to design the gain (K) of the system assuring stability for different delay situations. In addition, we can determine K from certain performance parameters, like the overshoot. In line with this control-based approach we refer to our proposal as Proportional Tracking Algorithm (PTA). Third, in order to assure stability under delay variations, we provide a simple procedure to reconfigure the gain according to the measured delay, resulting in an adaptive version of PTA. Fourth, theoretical results are validated through simulations. It should be noted that PTA is compatible with 3GPP specifications.

The rest of the paper is organized as follows. Section 2 analyzes the response of CA. Section 3 describes our proposal and its model as a discrete-time control system. Section 4 focuses on the stability and configuration of PTA, and presents its adaptive version. The validation of theoretical results through simulation is discussed in Section 5 including a performance evaluation under realistic traffic conditions in the Iub. Finally, Section 6 summarizes the contributions of this work.

2. Analysis of the classic algorithm

The transport channel synchronization procedure operates on each transport channel associated to a DCH in the downlink direction and relies on an estimation of the downlink delay (*offset*). If the *offset* does not differ too much from the actual delay, each frame is expected to arrive at the Node B within a reception window. If a frame arrives outside this window, the Node B responds with a Timing Adjustment (TA) frame containing the Time Of Arrival (TOA) of the received frame. The RNC uses this feedback information to adjust the *offset* and thus, the sending time instant of the next frame, trying to steer the arrival time of the frames into the window. This procedure is known as timing adjustment. If a frame arrives so late that it cannot be processed before its TTI, the frame is discarded. Fig. 1 shows the possible frame reception instants and the names of the temporal references. For a more detailed explanation of the related signalling the reader is referred to [4].

The classic timing adjustment algorithm (CA) basically adds or subtracts a constant value, K, to the *offset* if the TOA indicates a late or an early arrival, respectively. It is frequent to see this algorithm referred to the sending time instant [5]:

$$\begin{aligned} t_{n+1} &= t_n + t_{TTI} - K \quad \text{if } TOA < 0, \\ t_{n+1} &= t_n + t_{TTI} + K \quad \text{if } TOA > TOAWS. \end{aligned} \tag{1}$$

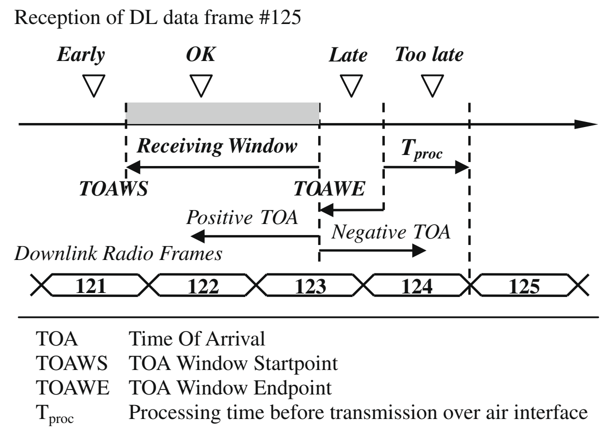

Fig. 1. Reception window in the Node B.

where t_{TTI} is the duration of a TTI and t_n is the transmission time instant of frame n. This algorithm can also be expressed in terms of offset corrections with the following equation:

$$\begin{aligned} offset_{n+1} &= offset_n + K \quad \text{if } TOA < 0, \\ offset_{n+1} &= offset_n - K \quad \text{if } TOA > TOAWS. \end{aligned} \tag{2}$$

The main advantage of CA is its simplicity. However, some aspects of this algorithm have not been fully investigated, e.g. how to suitably configure the step K and the window size considering the inherent oscillatory behaviour of the algorithm.

Because the signals involved in timing adjustment (the delay, the error and the offset), take one value per frame, we can model the CA algorithm as a discrete-time control system making the following assumptions. First, the source transmits one frame per TTI, i.e. there are no idle times for data traffic in the period under study. Second, the inter-departure time between consecutive frames in the RNC is constant and equal to t_{TTI}. Therefore we neglect the variation in inter-departure time caused by the offset correction done when TA frame are received. These assumptions are validated by means the simulator presented later in Section 6.

Fig. 2 illustrates the operation of the time adjustment mechanism in a late arrival situation. This figure shows the delays of the system and the correction (Δ) applied to the offset, which equals to the time advance applied to the transmission time instant of frame n. According to (2), $\Delta = K$ if $TOA < 0$ and $\Delta = -K$ if $TOA > TOAWS$. We define the Round Trip Time (RTT) of the system as the time elapsed between the sending time of a frame and the moment when the TA frame is applied to another frame. The number of TTIs in the RTT is $r = \lceil RTT/t_{TTI} \rceil$. Defining j and m as the downlink and uplink delay in TTIs, respectively, $r = j + m$.

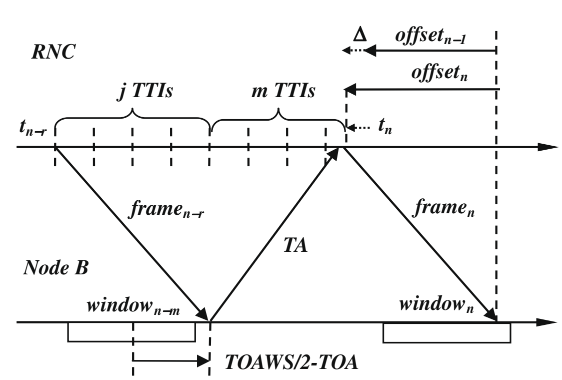

Fig. 2. Temporal diagram of the offset adjustment algorithm.