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Time Synchronization between the eNBs in E-UTRAN under the Asymmetric IP Network

M. Kollar, A. Zieba

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***Abstract*—**In this paper, we present a method for a time synchronization between the two eNodeBs (eNBs) in E-UTRAN (Evolved Universal Terrestrial Radio Access) network. The two eNBs are cooperating in so-called inter eNB CA (Carrier Aggregation) case and connected via asymmetrical IP network. We solve the problem by using broadcasting signals generated in E-UTRAN as synchronization signals. The results show that the time synchronization with the proposed method is possible with the error significantly less than 1 ms which is sufficient considering the time transmission interval is 1 ms in E-UTRAN. This makes this method (with low complexity) more suitable than Network Time Protocol (NTP) in the mobile applications with generated broadcasting signals where time synchronization in asymmetrical network is required.

***Keywords*—**E-UTRAN, IP scheduled throughput, initial burst delay, synchronization, NTP, delay, asymmetric network.

I. INTRODUCTION

LONG Term Evolution (LTE) advanced aims to support peak data rates of 1 Gbps in the downlink and 500 Mbps in the uplink. In order to fulfill such requirements, an extended bandwidth is required. LTE-Advanced proposed to use the bandwidth up to 100 MHz. However to have such available contiguous spectrum is rare in practice. That is why CA of multiple Component Carriers (CCs) of up to five 20 MHz CCs has been selected by LTE advanced as the most suitable option. All CCs in Release 10 are designed to be backward-compatible. This means that each CC can be configured to be accessible to Release 8 User Equipments (UEs). From the higher-layer perspective, each CC is acting as a separate cell with its own Cell ID. A UE that is configured for CA connects to Primary Serving Cell (known as the “PCell”) first and then to up to four Secondary Serving Cells (known as “SCells”). The PCell is defined as the cell, and the UE is doing Radio Resource Control (RRC) connection establishment and also with respect to security, Non Access Stratum (NAS) mobility information, System Information (SI), and some RLC, MAC and physical layer functions. After the initial security, activation procedure up to four SCells may be configured in addition to PCell for the UE. The RRC Connected UE shall always be connected to one PCell and may also contain one or more SCells. The number of configured SCells depends on the UE capability. There is only a single RRC connection which is established with the PCell and controls all the CCs configured for a UE. Thanks to a new functionality, now UE is able to connect to SCells that are even from different evolved NodeBs (eNBs), but still the PCell connection must remain in the eNB from which UE originates, where UE has established default bearer connection. The communication between PCell and SCells in terms of Inter eNB CA shall take places over X2 interface [8]. In order to obtain proper IP scheduled throughput measurements for inter site CA, according to TS 36.314 [10], a constant message exchange would be needed over X2 interface with the time for sending specific data volume packet in the certain SCell. What is more, full time synchronization would be required between PCell and SCells, taking part in CA. This paper presents an alternative way to obtain such measurements via providing full time synchronization based on already existing mechanisms, such as Master Information Block (MIB), System Information Block (SIB) or Network Time Protocol (NTP).

Martin Kollar is with the Nokia Solutions and Networks, Poland (e-mail: Martin.Kollar@nokia.com).

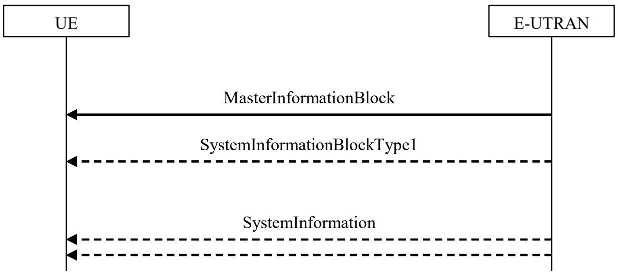


Fig. 1 System information acquisition, normal

System information transmitted on Broadcast Channel (BCH) is dived into MIB and SIBs that are delivering the most essential information UE needs to connect to the cell. The MIB transmission starts in subframe #0 of radio frames for which the System Frame Number (SFN) mod 4 = 0 with periodicity of 40 ms, and repetitions are scheduled in subframe #0 of all other radio frames. With the “MobilityControlInfo” IE, it is indicated in E-UTRAN whether optional MIB repetitions are enabled or not. The System Information Block Type1 (SIB1) uses a fixed transmission with a periodicity of 80 ms and repetitions done within 80 ms. The first transmission of SIB1 is done in subframe #5 of radio frames for which the SFN mod 8 = 0, and repetitions are made in subframe #5 of all other radio frames for which SFN mod 2 = 0 [9].

The frequency synchronization between the eNBs in E-UTRAN is very precise (clock accuracy about ±0.05 ppm); however, in order to measure for example IP scheduled throughput and Initial scheduling delay according to 3GPP TS 36.314, for inter eNB CA scenario also a precise time synchronization between the eNBs is needed, where even time offset value couple of milliseconds can be a critical issue. GPS

(Global Positioning System) as a reference clock done via PPS (Pulse-Per-Second) is considered as high accurate (nanoseconds) and thus enables very precise frequency synchronization between the eNBs. However, PPS does not contain any more information than when a second start. Therefore, the "GPS time" from the GPS "data outlet" can be off by tens or hundreds of ms which is unacceptable for IP scheduled throughput and Initial scheduling delay according to 3GPP TS 36.314 [10]. The time synchronization between the eNBs may be done using the Network Time Protocol (NTP).

NTP is the very popular computer clock synchronization protocol for the computer network. Today, we can obtain the accurate time via Internet easily. The NTP estimates a clock offset (θ) and a round trip delay (δ) between two computers as:

$$\delta = (t_3 - t_0) - (t_2 - t_1) \tag{1}$$

$$\theta = \frac{((t_1 - t_0) + (t_2 - t_3))}{2} \tag{2}$$

where t_0 is a transmitted time of a request packet, t_1 is a received time of a request packet, t_2 is a transmitted time of a reply packet, and t_3 is a received time of a reply packet [2].

Considering the example in Fig. 2, the θ is, according to (2), given as follows: ((135 ms – 231 ms) + (137 ms – 298 ms))/2 = -128.5 ms. This means that there is a time difference in time measurement on Client side comparing to Server side, which is 128.5 ms. To synchronize the time on Client side the master clock of the Client shall be corrected by subtracting 128.5 ms. The corrected t_0 marked as $t_{0'}$ is then 102.5 ms and t_3 marked as $t_{3'}$ is then 169.5 ms. This considers that outgoing and incoming routes are equal and take 32.5 ms (135 ms – 102.5 = 169.5 ms – 137 ms), and only in this case the NTP gives correct time synchronization. In other words, the difference of these routes causes that the clock offset has a bias approximate a half of the difference [1]. So, given to the same example if for instance outgoing route was 40.5 ms and incoming then 24.5 ms, (1) would give that θ = 120.5 ms, i.e. the error in time synchronization is 8 ms (128.5 -120.5) which is exactly half of the difference of the routes ((40.5 ms – 24.5 ms)/2).

II. METHODS IMPROVING NTP TIME OFFSET UNDER THE ASYMMETRIC NETWORK

The existing methods improving NTP time offset under the asymmetric network as described in previous chapter can be divided to two groups:

A. Methods Based on t1-t0 and t2-t3 Measurement Adopting the Network Bandwidth Estimation Method

Typical example is a method published in [1] based on Packet Pair/Train Dispersion Probing for the bandwidth estimation. However, the problem for that method is related to cross traffic, which is some other traffic transmitted over the same IP route. Unfortunately, it is high probable that some other traffic is going to be transmitted over the same IP route. In addition, cross traffic can in addition increase or decrease the time difference between outgoing and incoming IP routes. This will simply lead to a situation when the time synchronization between Client and Server is impossible to reach, because increased or decreased delay shall further desynchronize data synergy between two nodes. Furthermore, statistical methods to increase number of probes in the measurement might help to decrease the error in bandwidth estimation, but still the precision is not reliable and the importance of error margin shall persist [7]. Thus, generally adopting the network bandwidth estimation to solve this issue is questionable as it can be done precisely only as an average value from thousands of samples which do not represent the exact point of time the outgoing and incoming route messages were sent.

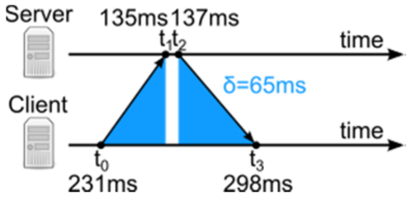


Fig. 2 Clock offset (θ) and a round trip delay (δ) measurement using the NTP method [2]. As client an eNB in E-UTRAN can be seen

B. Methods Based on Reversing a Direction of Transmission

Principle is based on measurement of time offset first as indicated in Fig. 2 then exchange the position of Server and Client and to measure the same again and then average time offsets from these two measurements. This method is described in [3], [4]. However, this method is applicable only for the scenarios when the Server and Client can be switched over which is not the case for the eNBs in E-UTRAN.

III. NEW METHOD IMPROVING NTP TIME OFFSET UNDER THE ASYMMETRIC NETWORK

The method intends to obtain the time synchronization between two eNBs in E-UTRAN by measuring θ from eNB1 point of view (see Fig. 2), given as:

$$\theta = t_1 - t_0 \tag{3}$$

where t_0 and t_1 are measured with the help of an external synchronization signal, represented as series of impulses, each next two located on the same time interval which is higher or equal than δ according to (1). On the occurrence of the *(n)th* impulse in eNB1, an Internal Request message is sent from eNB1 to eNB2 to instruct the eNB2 to listen for the given *(n+1)th* impulse message. A time stamp t_0 shall be taken on eNB1 when the impulse *(n+1)th* was transmitted by eNB1. At the same point of time, a time stamp t_1 shall be taken on eNB2 when the impulse *(n+1)th* arrived on eNB2. Afterwards the eNB2 shall send Internal Response message to the eNB1, which shall contain the t_1 value. The eNB1 then calculates θ according to (3) and corrects each point of time measured by this value.

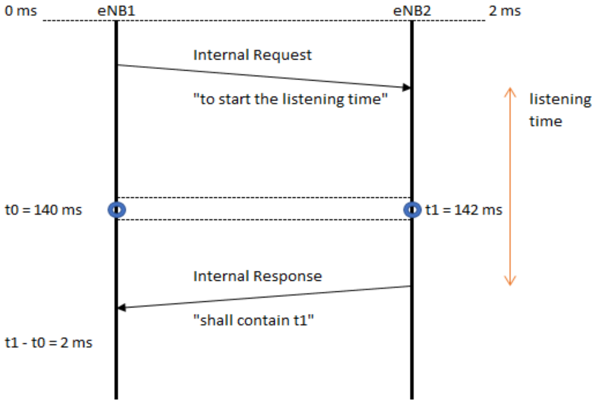


Fig. 3 Modified NTP with θ calculation on eNB1 side

Based on this method, we do not need to check for the asymmetry of the IP link routes, because the time synchronization between two eNBs shall be corrected regardless of it. Error in time synchronization based on this method is then directly equal to time interval needed to transmit the *(n+1)th* impulse from eNB1 to eNB2. To have this error on an acceptable level, the appropriate fast interface must be chosen for sending the *(n+1)th* impulse from eNB1 to eNB2.

IV. IMPLEMENTATION OF THE METHOD IN REAL E-UTRAN NETWORK

The method described in previous chapter intends to obtain the time synchronization between the two eNBs in E-UTRAN where the eNBs are cooperating in so called inter eNB CA case [8]. CA of multiple CCs is used to achieve high-bandwidth transmission. LTE-advanced supports the maximum bandwidth of 100 MHz achieved via configuration of four SCells and one PCell. The PCell is the cell the UE is doing RRC Connection setup. It plays an essential role with respect to security, NAS mobility information, SI for configured cells, and some lower layer functions [9]. In case PCell and one or more SCells are physically located in different eNBs we are speaking about inter eNB CA. The communication between PCell and SCells in terms of Inter eNB CA shall take place over X2 interface realized on IP layer [8]. To measure then IP scheduled throughput according to 3GPP TS 36.314 in case of inter eNB CA, which is given as ratio of PDCP SDU (Packet Data Convergence Protocol Serving Data Unit) volume for all CA UEs and total UE time when there were data in the buffer excluding last Time Transmission Intervals (TTIs) both from numerator and denominator, it considers there is a time difference much less than 1ms in time measurement between eNBs. This is because 1 ms, one transport block duration, is a resolution in time measurement for IP scheduled throughput. Also, initial scheduling delay per burst is measured with the same time resolution according to 36.314 [10]. Considering these facts, the error on the range from ones up to hundreds of µs in time synchronization between the eNBs is acceptable.

Mandatory condition to configure an UE with the PCell and one or more SCells in different eNBs is that the configured PCell and SCells have approximately the same coverage. It means that each message sent from PCell eNB is in the range of reception of SCell eNBs. The principle of the method as depicted in Fig. 2 considers an external synchronization signal between the eNB1 (as PCell related) and eNB2 (as SCell related), which in order to obtain acceptable error in time synchronization shall be transmitted via fast interface. Related to inter eNB CA case, we propose to use air interface and to use MIBs as external synchronization signal where the transmission time for example between the eNBs with antennas located on distance 300 m will take 1 µs (300/3*108). The new MIBs are generated once per 40 ms, which gives sufficient time to receive the Internal Request message from eNB1 (sent on occurrence of (n)th new MIB) by eNB2 and run listening algorithm [6] on eNB2 to receive (n+1)th new MIB from eNB1 because according to X2 interface backhauling requirements 10, max 15 ms is end-to-end round trip delay [5]. So, the 40 ms could even be sufficient also for inter eNB CA for cloud scenarios [8]. Regarding the new MIB, the MIBs that are generated with SFN mod4 =0 are meant, because there are also repeated MIBs between the new ones that are generated once per 10 ms. As depicted in Fig. 3 the t1 is the point in time measured in eNB2 when (n+1)th new MIB is received from eNB1, which in details means the point in time when first part of the MIB has been received in eNB2 because depending on the radio conditions not only new but some of the next repeated MIBs can be used to correctly decode the new MIB. The (n+1)th new MIB is not correctly received and possible decoding on next, i.e. (n+2)th new MIB would lead to incorrect time synchronization between the eNBs with error higher than 40 ms. Therefore, it is recommended to transmit within Internal Request message also the SFN of the (n+1)th new MIB. In the case where the (n+1)th new MIB with the indicated SFN is not received by eNB2, then such synchronization cycle shall be evaluated as invalid one and communicated to eNB1 via Internal response message as depicted in Fig. 3. As indicated above, the 40 ms shall give sufficient time to receive the Internal Request message from eNB1 by eNB2, synchronize with the cell of eNB1via Primary and Secondary Synchronization Signals (PSS and SSS) [8] and finally run listening algorithm [6] on eNB2 to receive (n+1)th new MIB from eNB1. However, there can be some scenarios like an overload situation within the eNB requiring longer time for synchronization which may require to instruct the eNB2 to read (n+2)th or even (n+3)th new MIB. In order to provide operator a possibility to monitor this case some performance measurements as defined in Tables 1 and 2 according to 3GPP TS 32.425 are recommended. Comparing the number of valid and invalid Internal response message, some decisions within the eNB1 to instruct the eNB2 to read (n+2)th or even (n+3)th new MIB may be taken.

After the MIB has been correctly received, the t1 is communicated via Internal response message from eNB2 to eNB1. The eNB1 then calculates θ according to (3) and corrects each point of time measured by this value.

TABLE I
DEFINITION OF THE MEASUREMENT RELATED TO THE NUMBER OF INTERNAL RESPONSE MESSAGE WITH INVALID STATUS ACCORDING TO 32.425

a) This measurement provides the number of Internal response message with invalid status when time synchronization between the observed and neighboring eNB was unsuccessful.
b) CC (Cumulative Counter)
c) This measurement pegged on each reception of the Internal response message with invalid status.
d) Each measurement is an integer value
e) The measurement name has the form eNBInvalidInterResp
f) eNB

TABLE II
DEFINITION OF THE MEASUREMENT RELATED TO THE NUMBER OF INTERNAL RESPONSE MESSAGE WITH VALID STATUS ACCORDING TO 32.425

a) This measurement provides the number of Internal response message with valid status when time synchronization between the observed and neighboring eNB was successful.
b) CC (Cumulative Counter)
c) This measurement pegged on each reception of the Internal response message with invalid status.
d) Each measurement is an integer value
e) The measurement name has the form eNBInvalidInterResp
f) eNB

As losing the time synchronization between the eNBs is rather a function of a very slow changing function in time, it is sufficient to run such synchronization cycles once several hours or days. It is recommended to do it during the night time when there is a low amount of traffic. In the case where more than one SCell is configured for CA and all of them are located in different eNBs, the synchronization cycle shall be run separately between the PCell's eNB and corresponding SCell's eNBs.

The final method principle where new MIBs are used as external synchronization signal is depicted in Fig. 4.

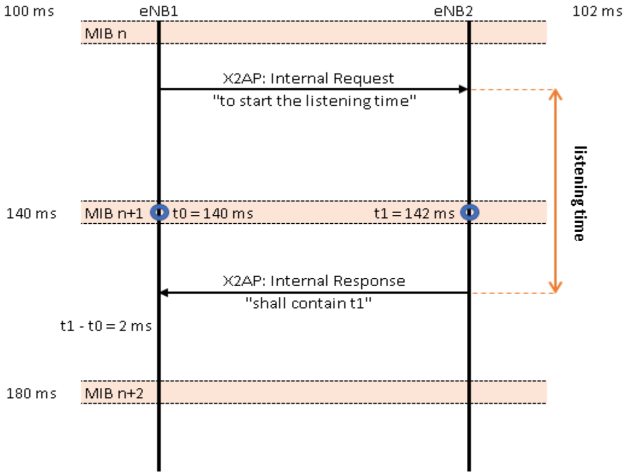
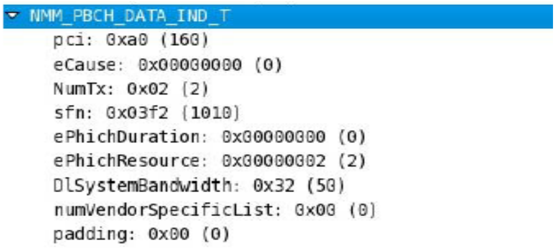


Fig. 4 Method principle where new MIBs are used as external synchronization signal

As it can be observed, the Internal Request message and the Internal Response message are transmitted via X2 interface between the eNBs, while the MIBs are broadcasted on eNB1 air interface. It shall be noted that there can be some vendors with synchronization signal transmitted between the eNBs via cable (not via IP). In the case where there is time interval between two synchronization impulses 40 ms or more, then this can be used as another option how to implement the invention.

V. ADVANTAGES OF THE PROPOSED METHOD

The method is based on re-using the MIB message. Two new messages: Internal Request message and Internal Response message are requested to be exchanged between the eNB1 and eNB2 through already existing X2 interface. However, because inter eNB CA is enabled between the eNBs of the same operator it is not needed to standardize them in 3GPP.



```
▾ NMM_PBCH_DATA_IND_T
    pci: 0xa0 (160)
    eCause: 0x00000000 (0)
    NumTx: 0x02 (2)
    sfn: 0x03f2 (1010)
    ePhichDuration: 0x00000000 (0)
    ePhichResource: 0x00000002 (2)
    DlSystemBandwidth: 0x32 (50)
    numVendorSpecificList: 0x00 (0)
    padding: 0x00 (0)
```

Fig. 5 MIB received from neighbouring cell using the Network Monitoring Mode as described in [6].

The biggest part that shall be implemented to run the method is reception time of the first part of the $(n+1)^{th}$ new MIB identified via SFN transmitted in the Internal Request message from eNB1 to eNB2 which is already implemented as indicated in [6] where a new MIB in the example as in Fig. 5 can be received from neighboring cell.

VI. PRECISION OF THE PROPOSED METHOD

Following (3), possible sources of the error are coming from measurement of the t_0 and t_1. Both for t_0 and t_1, the error depends on a difference between the point in time the synchronization was physically sent and received, and when it is internally measured in eNB1 and eNB2, respectively.

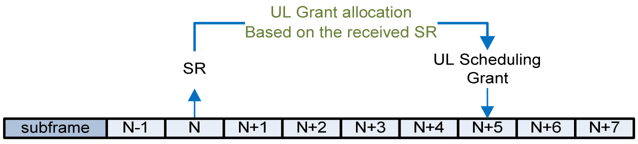


Fig. 6 Internal eNB processing time needed to proceed SR nessage

A non-zero internal eNB processing time is needed for each message. For example, to proceed Scheduling Request (SR) from UE and send corresponding UL Scheduling Grant the eNB needs about 5 ms as indicated in the following Fig. 6.

The internal eNB processing time, given as a difference in the point of time the message, is received and the content of the message is available for further processing, is set to a bigger value than in fact is needed to have it independent on the eNB load. The exact point in time where the message has

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been received by eNB can be obtained with backward compatibility considering the internal processing time is a fixed value. Therefore, this source of an error can be omitted.

Regarding the t_1 additional source of an error is the time interval that MIB message needs to travel from eNB1 to eNB2. However due to fact that for inter eNB CA, it is mandatory that both eNB1 and eNB2 have the same coverage, also this source of an error can be omitted because the time synchronization is required with resolution 1 ms (see also chapter IV).

VII. CONCLUSION

A very simple method enabling time synchronization between the eNBs that are cooperating in so called inter eNB Carrier Aggregation case to evaluate IP scheduled throughput and Initial burst delay measurements according to 3GPP 36.314 has been presented.

The advantage of the method is that, without any difficult algorithms, a time synchronization between the two eNBs is obtained based on a synchronization signal which is generated by PCell eNB. Last but not least, the precision of the proposed method implemented in eNB of E-UTRAN shall guarantee the error significantly less than 1 ms which is sufficient for reliable IP scheduled throughput and Initial burst delay measurements according to 3GPP 36.314 considering the Time Transmission Interval (TTI) in this technology equal to 1 ms.

Further research shall focus on using an alternative for MIB, as a synchronization signal, because some vendors may find it difficult to implement it, as it is based on monitoring of neighboring cell/eNB. The proposal which is going to be further analyzed is based on the usage of "Setup Request" message that is used to establish dedicated interface between the eNBs in inter eNB CA case.

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