Fronthaul Timing Imbalance Impact on User Equipment Positioning in 4G and 5G

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Abstract *Time difference measurement by RAN is one of the trilateration based UE's positioning techniques. We propose a discussion about the impact of optical fronthaul timing on the positioning performance. Experimental measurements for several Wavelength Division Multiplexing fronthaul implementations are presented with a focus on latency.*

Introduction

Positioning technologies for mobile devices become even more important for future connected digital applications in production, logistics, security, emergency services and vehicular use cases[1]-[3]. 5G should enable, and improve if suitable, state-of-art positioning techniques that are embedded or not in Radio Access Network systems (RAN-embedded[4] and RAN-external respectively). In this paper, we will focus on RAN-embedded technologies with techniques based on Cell-ID, Enhanced Cell-ID, downlink angle of departure, uplink angle of arrival, multi-cell round trip time and down- & up-link time difference of arrival[5]. Those measurements allow us to focus exclusively on the differece of time-dalays in the fronthaul interface.

Principle of time difference measurements

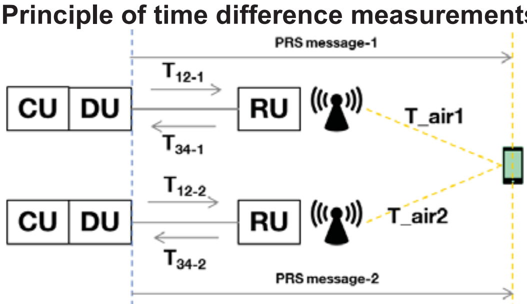

Fig. 1: Reference Signal Time Difference timing parameters

The downlink time-based positioning techniques of User Equipment (UE) devices take advantage of the timing difference between several neighbors Digital Units (DU) and the UE to calculate the distance by estimating the Time Of Arrival (TOA) or Time Difference Of Arrival (TDOA) of specific radio signals. The Positioning Reference Signals (PRS) are initialized by the Radio Resource Control (RRC) layer at the CU in relation with the associated DU where time stamping is acheived. The UE measures with multiple iterations the Reference Signal Time Difference (RSTD)[6] between a pair of CUs and DUs corresponding to these PRS. In other words, RSTD corresponds to the difference of flight time between two cell sites (CU&DU) for the UE. The PRS crosses the mid-haul and fronthaul segments (the latter separating the DU and the Radio Unit - RU), the RU itself and the air segment before reaching the UE. For the fronthaul network segment, we consider the downlink T_{12} and uplink T_{34} timing shown in Figure 1, which summarizes all these timing parameters for RSTD measurements. Now for matters of simplification and without loss of generality, we are only considering in our RSTD calculation the air and fronthaul segments delays as (we consider static and/or known delays through the RU, DU and UE frontends):

(1) $RSTD \approx (\mathrm{T}_{12-1} + \mathrm{T}_{\mathrm{air1}}) - (\mathrm{T}_{12-2} + \mathrm{T}_{\mathrm{air2}})$

Assuming that the location algorithm knows each T_{12} for each DU, we can deduce the relevant positioning timing $\mathrm{T}_{\mathrm{air1}} - \mathrm{T}_{\mathrm{air2}}$ by subtracting T_{12-1} and T_{12-2}. We will consider two cases: a fronthaul equipment supporting only frequency synchronization, which is the typical case for 4G CPRI-based interfaces, and fronthaul equipment supporting phase/time synchronization which should be deployed with 5G eCPRI or O-RAN 7.2x based interfaces.

For 4G fronthaul (CPRI-based)

When the RU is only frequency synchronized, the timing of the fronthaul is measured by the DU with a round trip delay. T_{12} is thus estimated as half a round trip time (cf. Fig. 2). When we have an asymmetrical delay fronthaul ($\mathrm{T}_{12} \neq \mathrm{T}_{34}$) we have an RSTD error of about $(\mathrm{T}_{12-1} + \mathrm{T}_{34-1})/2 - (\mathrm{T}_{12-2} + \mathrm{T}_{34-2})/2$. Of course other contributions for uplink/downlink asymmetry could be considered but we focus here only on the fronthaul transmission.

Fig. 2: 4G Fronthaul timing measurement

For 5G fronthaul (eCPRI-based)

eCPRI fronthaul is based on Ethernet. It supports PtP/SyncE to achieve phase/time synchronization at RU. In this case, a one way measurement is possible because DU and RU are synchronized with a relative Time Error (TE) in relation with Primary Reference Time Clock (PRTC). The fronthaul asymmetry is considered to be part of the contribution to the TE that must be below the required RSTD resolution. Three points must be noted: the T_{12} measurement is performed by the Control-Plane, the synchronization has its dedicated Sync-Plane, and finally the PRS is embedded in the radio resource element map in the User-Plane. Due to these different references at different levels, the time of the T_{12} measurement and PRS transmission could differ. Such time difference in combination with Ethernet transport jitter and wander could have a considerable impact on RSTD precision (cf. Fig. 3).

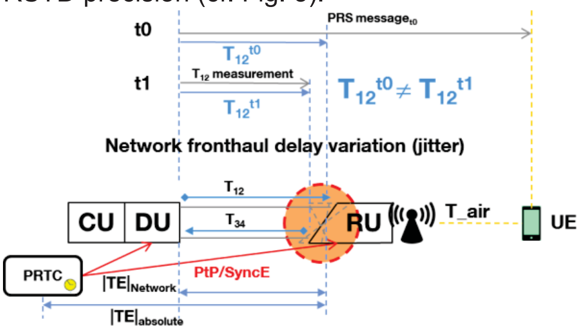

Fig. 3: 5G Fronthaul timing measurement

Timing values for RSTD

For 4G, the RSTD timing values are defined by 3GPP in function of the basic timing unit called "Ts". For 4G and 5G, Ts value is 1/(2048xFs) and 1/(4096xFs), respectively, with Fs the subcarrier spacing frequency. Fs is equal to 15 kHz for 4G, 30 kHz for 5G low carrier frequency (carrier frequency lower than 6 GHz in FR1) with 100 MHz bandwidth, and 120 kHz for 5G high carrier frequencies (typ. 26-30 GHz, in FR2). For 4G, the minimum RSTD resolution is equal to Ts (Ts/2 for high accuracy mode). The UE RSTD measurement accuracy error is ±4xTs. Because 5G RSTD is not yet defined, we propose to re-use the same 4G calculation based on Ts for 5G (cf. Tab. 1).

For 4G fronthaul with only frequency synchronization, the asymmetrical delay must be strictly bellow the RSTD resolution (<<32.6 ns). For 5G fronthaul, the relative and absolute fiber asymmetry is defined bellow the required RU TE (based on Sync. plane) which must be also bellow the RSTD resolution. Presently, O-RAN specification[7] proposes relative TE margins to take into account transport asymmetry between 12 and 60 ns depending on synchronization features. But these specifications are proposed while excluding TDOA applications. We can consider that requirements without radio positioning (previous column) thus as the minimum requirements for supporting radio positioning based on time measurements.

Tab. 1: RSTD timing values standardized for 4G and calculated for 5G

Unit (ns)	4G	5G FR1	5G FR2
Ts	32.6	*8.1*	*2*
RSTD resolution	32.6	*8.1*	*2*
RSTD accuracy	± 130	*± 32.6*	*± 8,1*

Optical fronthaul

Fronthaul transport delays T_12 and T_34 could have propagation time asymmetry, wander and jitter, caused by:
- Difference of optical fiber lengths when uplink and downlink use separate fibers (7 m of standard single mode fiber approximatively corresponds to a 34 ns delay),
- Difference of wavelength propagation times when wavelengths are not close for uplink and downlink (typically 1.3 µm and 1.55 µm wavelength diplex causes a ~33 ns time difference over 20 km of standard single mode fiber ITU-T G.652).
- The cable length variation due to temperature changes (40ps/km/K is a typical value). So for 10 km and a temperature variation of 10°C, we obtain a 4 ns delay variation (wander).
- the difference of processing time (including functions such as time multiplexing, encapsulation, compression, advanced modulation format) and etc at the RAN equipment.

The most popular optical solution to support fronthaul is based on a direct fiber with two transceivers at the end faces. A bidirectional transceiver[8] allows to simplify fiber operations. An alternative would be based on wavelength division multiplexing (WDM) to decrease the number of required fibers.

WDM fronthaul

Table 2 summarizes the main technologies proposed in ORAN[9] to support the fronthaul link and their main characteristics for wavelength pairing.

Tab. 2: Wavelength pairing for fronthaul candidates

ITU-T standard	PtP bidi G.9806	MWDM	CWDM	DWDM (C-Band)
Number of channels	2	12	18	40 or 80
Wavelength	Down : 1330+/-10nm Up : 1270+/-10nm	1267.5 to 1374.5nm, 7 nm spacing,	1270 to 1610nm 20nm spacing	1528,77-1563,86nm 0,4 / 0,8nm spacing
Up/Downstream pairing		pairing by adjacent channels (1-2,3-4,5-6…)	Duplex pairing on different CH Bidi pairing within same CH	

Lately, bidirectional and duplex auto-tunable DWDM transceivers have been proposed to simplify operational wavelength management and field installation[10]. Using a pilot tone to negotiate the wavelength establishment, the DWDM transceivers can be inserted in any fronthaul terminations and will automatically adjust their wavelengths to the center frequency of the connected MUX channel. Following the experimental setup presented in Figure 4, we have been able to demonstrate error free transmission on the 40 DWDM channels with CPRI7 and 10Eth traffic. Up to 80km of SSMF with a maximum optical budget of 26dB were performed inserting the duplex auto-tunable transceivers in traffic testers, OLT PtP (Optical Line Terminal Point to Point) cards and switches. Different transceivers vendors were tested at network's both ends, guaranteeing interoperability of this new technology.

The wavelength and traffic establishment are immediate after a quick (<7s) disconnection and can last up to 3 minutes when a channel swap and full DWDM scanning are required.

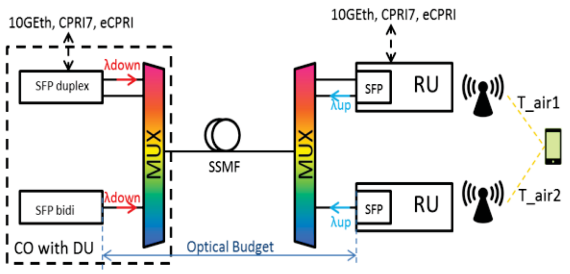

Fig. 4: Experimental Setup for WDM fronthaul

To achieve DWDM wavelength pairing when single fibre transceivers are used, both upstream and downstream signals crosses the same 100GHz MUX channel[11].

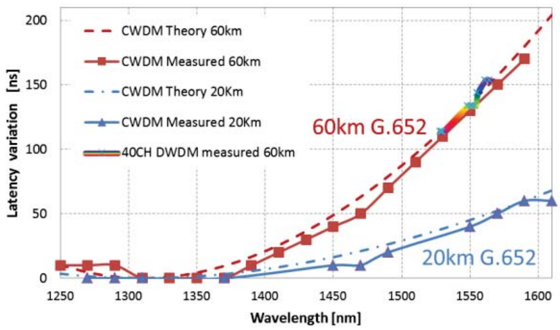

Fig. 5: Experimental and calculated latency difference vs wavelength for CWDM and DWDM channels

Bearing in mind RSTD limits defined previously, we also measured the latency variation according to wavelength variation in the DWDM range covered by the auto-tunable SFPs. With a resolution limited to 10ps, we extended those measurements to the full CWDM range and inserted 20km then 60km of G.652 fiber for better accuracy. Figure 5 displays those results taking a referential at 1310nm for zero latency. After 60km reach, we measured up to 40ns of latency difference between the lower and upper DWDM wavelength. That exceeds all RSTD resolutions requirements for geolocation reported in Table 1. For more accuracy and to extrapolate those measurements for different wavelength range and after 20km of fiber which is the maximum fronthaul reach, we plotted in Figure 6 the theoretical latency difference[12] for each fronthaul candidate identified in Table 2.

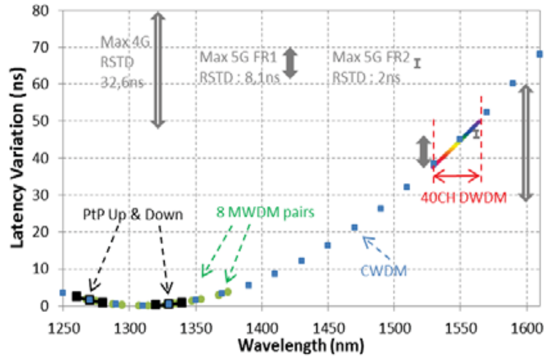

Fig. 6: Latency difference vs wavelength for several fronthaul technologies over 20km G.652

We observe that transceivers with optical career pairs in the O-band will lower the latency deviation: Bidirectional Point to Point, single Fiber DWDM and MWDM are the only solutions whose upstream and downstream wavelength pairs permits to maintain a latency difference below 2ns, as expected for the most stringent RSTD value for 5G FR2. The maximum RSTD resolution expected for 4G (32.6ns) could be met for CWDM but that would require a specific group of wavelength pairing with a maximum of 80nm spacing between paired channels. Similarly duplex DWDM pairing should be defined within channel subgroups with a maximum paired channel spacing of 22.5nm (29CH) and 6.4nm (8CH) for the maximal RSTD required respectively for 5G FR1 and FR2.

Conclusions

Use End devices geo-positioning through RAN networks are discussed and requirements on Reference Signal Time Difference are presented. Constraints on the fronthaul optical technologies, especially on DWDM and CWDM are experimentally highlighted with limitations on pairing wavelength spacing.

Acknowledgements

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