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ABSTRACT

This paper presents a foundation for a generic transmission format to be used in G.fast. The main goal of this proposal is to define a simple format that conveniently works for both STDD and STDMA implementations, allowing also combining them, if required, in a hybrid system. The proposed format is very similar to one used in VDSL2, but also allows operation of G.hn-based modems with very minor modifications.

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1 Introduction

The main principles of G.fast formatting and possible foundations for transmission formats were described in [1], [2], and [4]. The main attempt of both papers was to develop a format that can be used for both synchronous TDD (STDD) transmission mode and for synchronous TDMA (STDMA) transmission mode, as they defined in [1], [4]. It was shown in [2] that this is easily possible with a basic time-division approach.

In case of STDD (also referred as P2P), the transmission format is a traditional OFDM time-division duplexing format containing interleaved upstream and downstream, with synchronized upstream and downstream timing in all lines connected to the DP, similar to one used for SDMT VDSL, [3]. In case of STDMA (also referred as P2MP), the same principle can be used, however different groups of upstream and downstream symbols are transmitted over different lines, in the order assigned by a Medium Access Plan (MAP). Thus, a common transmission format can simply serve for both STDD and STDMA modes. This can also be observed from examples presented in [2].

This contribution proposes a unified format for both STDD and STDMA which is based on the principles proposed in [1], [2] and uses the traditional VDSL2 superframe approach. The basics of the proposed format are:

- Time division duplexing (no simultaneous transmission of upstream and downstream);
- The IDFT size and sub-carrier spacing used by all lines, both in upstream and downstream, are the same;
- The duration of US and DS symbols in all lines is the same (same values of CP).

2 G.fast frame format

2.1 Overview of STDD and STDMA

The two architectures were recently proposed for a DP operation, [4]:

- a synchronous TDD (STDD), in which each line is connected to its individual G.fast transceiver at the DP, Figure 1a;
- a synchronous TDMA (STDMA), in which all lines at the DP are connected to a single transceiver via line interface, Figure 1b. In STDMA one single transceiver at the DP transmits to and receives from all CPEs transceivers connected to all lines.

The terminology used in this contribution and the functionality described correspond to the block diagrams in Figure 1a and Figure 1b, respectively.

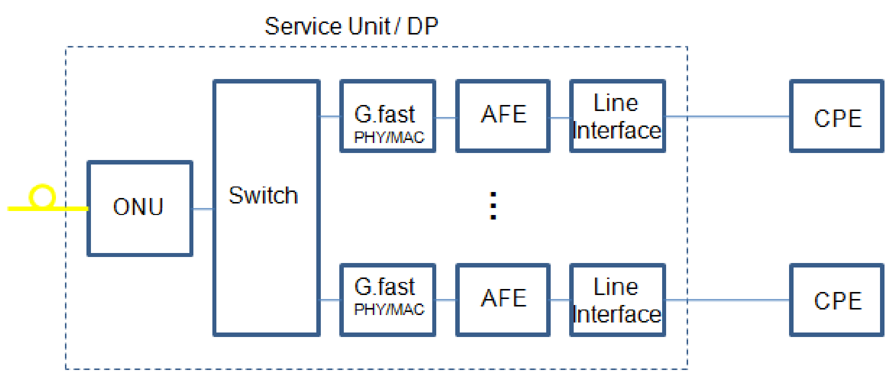

Figure 1a - DP with STDD architecture (individual transceivers per line)

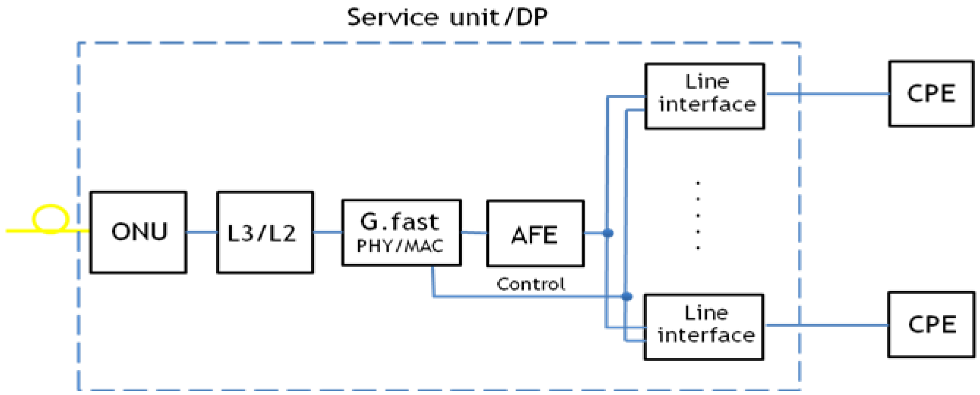

Figure 1b - DP with STDMA architecture (single transceiver serves multiple lines)

The proposed format also supports a case when DP uses a combination of both modes.

2.2 Superframe

The basic transmission format is a superframe shown in Figure 2.

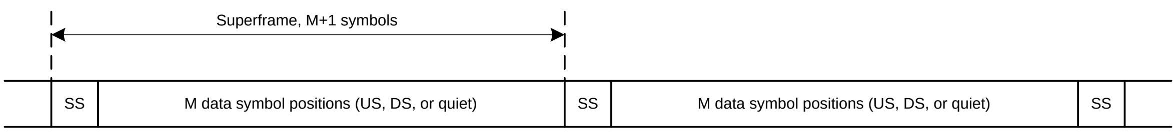

Figure 2 - G.fast superframe structure

The superframe contains M+1 symbol positions; it starts from a syncsymbol (SS) followed by M data symbol positions, where "data" is a general term used to identify actually transmitted symbols (user data, control or management data, or symbols with special content, like probe symbols) or quiet symbols, filling up the time when no transmission occurs. Superframes follow one after another with no gaps. All symbols in a superframe have the same duration, which depends on the selected value of cyclic prefix. The SS shall be transmitted in DS direction.

The exact number of data symbols in the superframe is beyond the scope of this contribution; it shall be picked in a way that at least allows CPEs to maintain stable synchronization and, if necessary, acquire reliable and convenient estimation of FEXT channels by using SS (similarly to G.993.5).

NOTE: In VDSL2 SS is sent every 256 symbols which results in a SS period of 64ms for 8-MHz and 17-MHz profiles, and 32ms for the 30-MHz profile. The latter may be also a good starting value of superframe duration for G.fast, although smaller superframe durations may be also selected, down to several milliseconds.

2.3 STDD operation

In case of STDD transmission, groups of successive symbols inside a superframe are assigned for US and DS, interleaved with each other; the number of US and DS groups is the same. The SS shall be sent in the DS direction; US transmissions may also contain SS, if necessary (e.g., for vectoring, signaling, or other purposes); if SS are transmitted in the US, they shall be transmitted once per superframe, on same position in all superframes. The position of SS shall be aligned over all lines, both in DS and in US (if SS are used in US). The position of all data symbols, accordingly, is also aligned between all lines, both in DS and in US directions.

Figure 3 shows an example of a superframe for STDD that includes three DS-US transmissions: all the DS periods have the same duration and all the US periods have the same duration inside a given superframe. The number of symbols for DS and US is first determined during system initialization and may be modified seamlessly during showtime by using an appropriate management protocol.

Figure 3 – An example of a superframe that includes three DS-US transmissions

All lines connected to the DP in STDD mode shall use the same superframe and modify the DS/US ratio, if required, simultaneously. All DS transmissions and all US transmissions shall be synchronized in all lines to avoid NEXT.

Figure 4 illustrates a multi-line STDD example in which one US and one DS transmissions are established during a superframe.

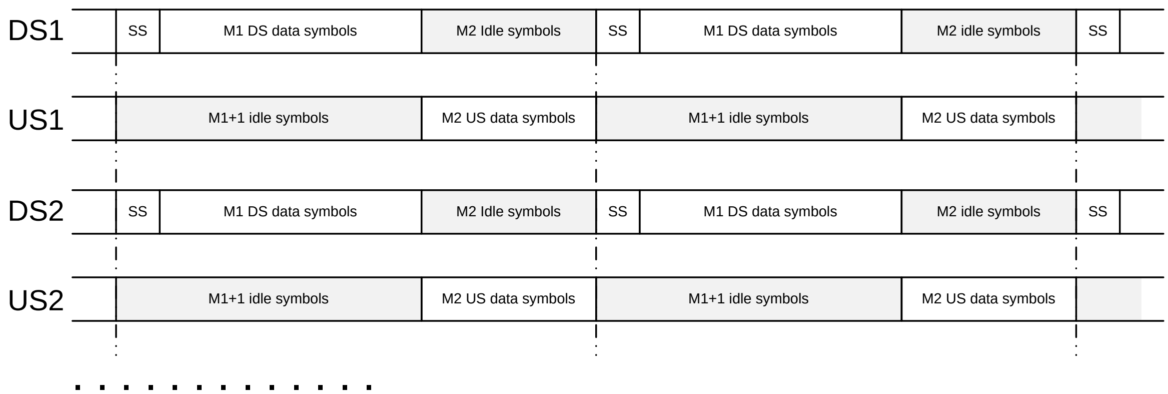

Figure 4 – Transmission timeline for STDD case: (case of one DS-US transmission per superframe)

2.4 STDMA operation

In case of STDMA transmission, groups of successive symbols inside a superframe are assigned for US and DS of different lines connected to the DP, and may have an arbitrary order. The SS shall be sent in the DS direction, but US transmissions may also contain SS, if necessary, also transmitted once per superframe, on same position in all superframes. Same as in case of STDD, the position of SS shall be aligned over all lines, and the position of data symbols shall be aligned over all lines, both in DS and US directions.

Figure 5 (on the top) shows an example of a superframe including periods of US and DS transmission for two lines, #1 and #2, respectively. Below, it shows transmission timelines on each line in the US and DS directions. SS are transmitted only in the DS, aligned among all lines. All US and DS transmissions are also aligned to avoid FEXT and NEXT between lines sourced by the DP.

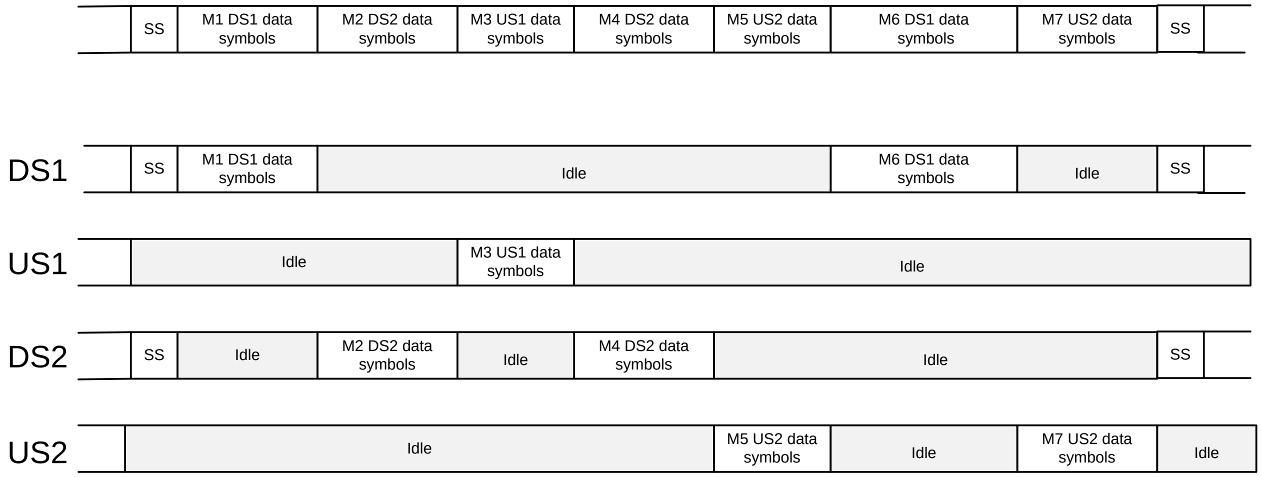

Figure 5 – Example of a superframe and a corresponding STDMA transmission timeline (2 lines)

Note, that in case lines of the same drop cable are connected to more than one STDMA group, time slots assigned to some of the lines connected to different DP may be collocated in time (in case FEXT between these lines is sufficiently weak or is mutually cancelled, see also section 2.8.

2.5 Transmission time slots

The superframes are divided into two or more groups of consecutive symbol positions for DS and US transmission. This division is convenient to be described by a set of time slots (TS), where each slot indicates the line that can be used for transmission (k = 1, 2,.. L) is a particular direction (US or DS). In other words, each TS indicates a transmission opportunity for a specific line in US or DS: TS_{DS-k}, TS_{US-k} denote, respectively, time slots for upstream and downstream transmission for line k. The set of TS defining a superframe is communicated in a so-called Medium Access Plan (MAP) message. All TS shall have a duration that is an integer number of symbols. The downstream SS has its default TS_{DS-SS}, while all other TS are programmable: their assignment and duration depends on the traffic requests from connected users.

Referring to the superframe example presented in Figure 3 (STDD), the MAP is the same for all lines and contains 2 values: TS_{DS} (M1 symbols) and TS_{US} (M2 symbols). The ratio between TS_{DS} and TS_{US} determines the US/DS bit rate ratio, while the sum $TS_{DS} + TS_{US}$ indicates the US-DS exchange cycle. The TS assignment for STDD is set at the initialization, but it may be changed under control of service provider (usually, as an extra-ordinary procedure). No dynamic re-assignment of TS is typically needed, so MAP needs to be updated at the CPEs very rarely.

Referring to the superframe example presented on the top of Figure 5 (STDMA), the following TS will be assigned (listed in the time order as in Figure 4): TS_{DS-1} (M1 symbols), TS_{DS-2} (M2 symbols), TS_{US-1}(M3 symbols), TS_{DS-2} (M4 symbols), TS_{US-2} (M5 symbols), and so on (no need, obviously, to mention the default TS for DS SS).

With STDMA, TS is dynamically assigned per line per direction, based on the particular service request from each CPE. Some TS may be assigned for all lines for broadcast (e.g., TS_{DS-SS}) or for more than one line (multicast, if the same information has to be sent to more than one CPE). These TS are usually for generic management and control information.

> NOTE: When a particular transceiver is granted a TS it may use the granted TS starting from any symbol of the TS, however the transmitter needs to indicate to the receiver the symbol from which the transmission starts. As an alternative, the transmitter may start transmission always from the first symbol of the TS and transmit idle symbols until valid data is available for transmission. The details of both types of operation are beyond the scope of this proposal.

2.5.1 Medium Access Plan

MAP is a control message that includes the list of TS assigned to all CPEs for transmitting and receiving of data symbols. The dynamic assignment of TS is done by broadcasting a MAP to all CPEs. The TS assignment may be defined as valid until the next MAP or as persistent, remaining valid for a defined period of time or is explicitly modified and "replaced". Besides the TS assignment, the MAP message may carry other management info on per-line/per-direction basis (e.g., bit loading, coding) and info of a common nature (e.g., regional tone mask or PSD limits).

MAP may be carried in a separate symbol, but it can also be conveyed by other means. It's convenient if the position of the MAP symbol is fixed in the superframe. However, sending a MAP in every superframe is often a non-justified overhead. In order to reduce this overhead while supporting dynamic behavior, MAP may be sent only in some superframes indicated to the CPE. Thus, the MAP can be potentially modified every superframe, i.e., with a very fine granularity (tens of milliseconds). Further details of MAP transmission are beyond the scope of this paper. In Figure 6, MAP follows the SS; the TS assignment and other parameters communicated in the MAP are valid from the superframe following the one in which MAP is transmitted.

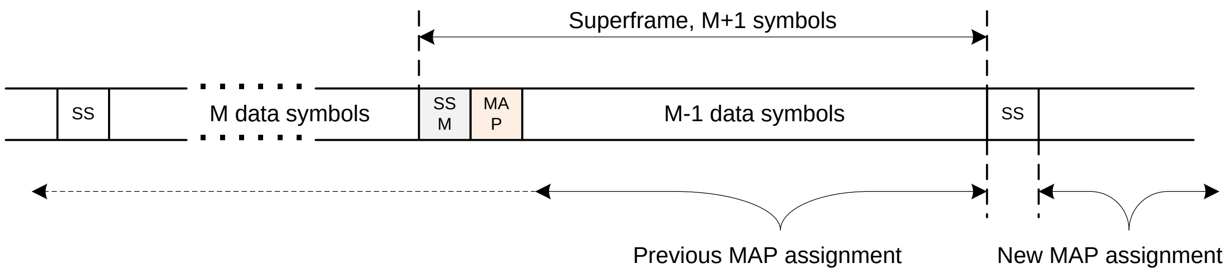

Figure 6 – A symbol carrying MAP follows a SS
(MAP symbol is not transmitted in the previous and subsequent superframes)

2.6 Transmission timing

2.6.1 Loop timing

All CPEs connected to the DP shall synchronize with the DP their sampling clocks and symbol timing. The SS are one source for clock synchronization. The particular content of the SS is beyond of this contribution, although a SS such as defined in G.993.5 is one of the possible structures. Additionally, DP shall be capable of transmitting few pilot tones to enhance robustness of CPE synchronization. In STDMA mode, pilot tones are broadcast, thus new lines may use transmitted pilot tones for initial clock/symbol synchronization. Superframe synchronization (which is needed for alignment of time intervals for DS and US transmission) is supported by SS.

In the upstream direction, symbols of all lines and superframes are also synchronized. To provide symbol synchronization, similar to VDSL2, the DP provides to each CPE the appropriate timing advance. The SS of multiple lines (if used) are aligned in time, for instance, by using time markers sent by the DP, similar to G.993.5.

2.6.2 Upstream timing

Upstream timing shall deal with the propagation delay in the line (T_d), which mainly depends on the length of the line and wire type. The value of T_d for the most of cable types is 2-5us per kilometer. For the 200m loops expected to be the longest in G.fast, the value of T_d doesn't exceed 1us, which is a small fraction of symbol duration (~25 us if 2048 carriers are used in 100MHz of frequency spectrum).

A guard time is usually also necessary between transmission and reception, to switch the AFE from transmission mode to reception mode, and vice versa. This case for STDD is presented in Figure 7. The DS transmission timing is aligned with symbol timing and same for the upstream.

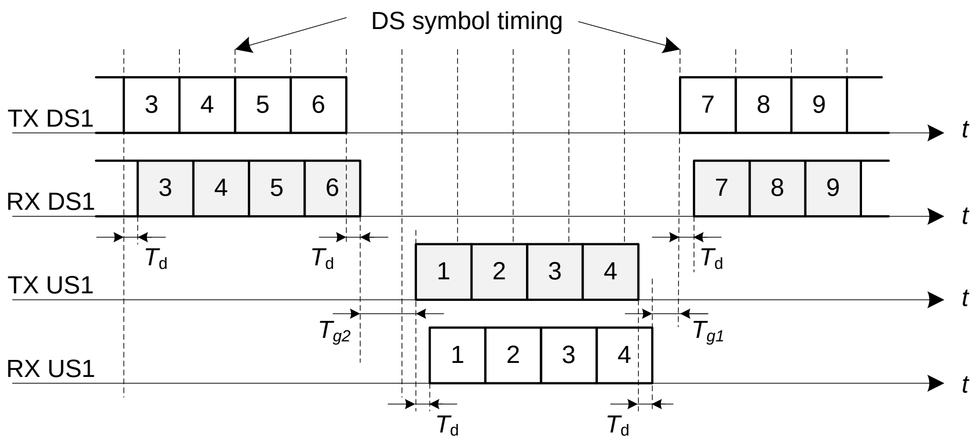

Figure 7 – STDD transmission timing at the DP (clear) and CPE (shaded)

To keep this alignment, the sum of the guard time at the CPE (T_{g1}) and at the CO (T_{g2}) shall satisfy equation [1]:

$T_d + T_{g2} + T_d + T_{g1} = n \times T_{OFDM}$, and $T_{g2} + T_{g1} = n \times T_{OFDM} - 2T_d$, [1]

where: n = 1, 2, … and T_{OFDM} is the symbol period. To provide the same guard time at the DP and at the CPE, $T_g = 0.5n \times T_{OFDM} - T_d$, and thus the minimum achievable guard time is $T_{g\text{-}MIN} = 0.5T_{OFDM} - T_d$ (which is roughly 1us less than half of the symbol duration). Longer guard times are allowed, but they must fulfill equation [1], which means that if the required value of guard time is higher than $T_{g\text{-}MIN,}$ the second valid value is $T_g = T_{OFDM} - T_d$, and so on, with granularity of selection equal $0.5T_{OFDM}$.

In case of STDMA, a guard time is necessary at the CPE when it shall transmit right after it receives (i.e., a $TS_{DS\text{-}k}$ is followed by a $TS_{US\text{-}k}$), but not necessary if transmission is granted to a CPE that doesn't need to turn from RX to TX. However, if DP transceiver operates in half-duplex mode, it requires a similar guard time to switch from TX to RX and back.

Figure 8 shows the case of CPE transmission over the same line (TX US1) and over the different line (TX US2) when DP operates in half-duplex mode. The guard time allowed for the DP ($T_{g2\text{-}DP}$) is by $2T_d$ bigger than the guard time selected by a CPE ($T_{g2\text{-}CPE}$), thus if CPE and DP require approximately the same time to switch from TX to RX and back, the value of the guard time T_{g2} determined by the CPE will provide sufficient guard time for the DP.

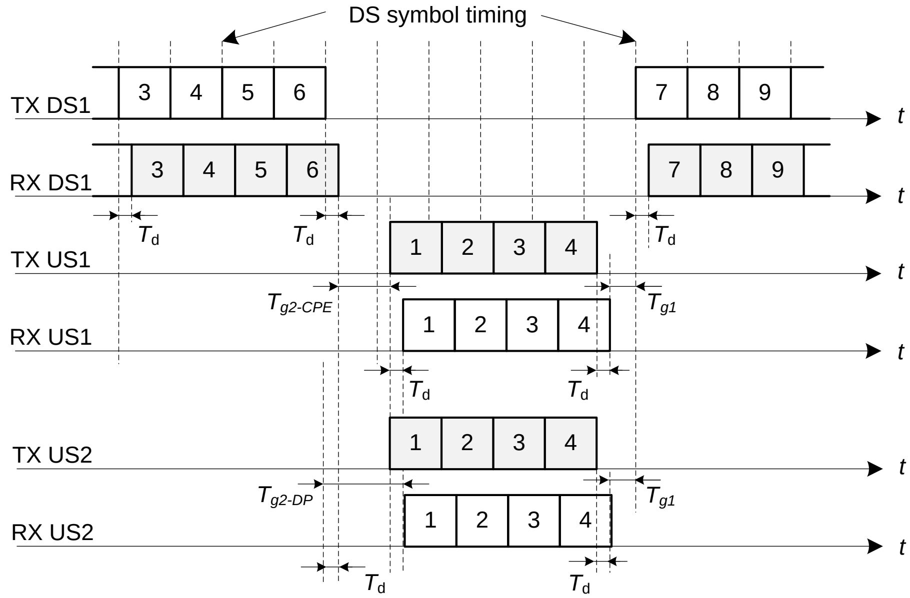

Figure 8 – STDMA transmission for timing at the DP (clear) and CPE (shaded); cases of a half-duplex DP and transmission from a CPE right after reception (US1) and from a CPE in idle state (US2)

If the transceiver at the DP operates in a duplex mode, i.e., a DP is implemented with a capability to transmit and receive simultaneously, the value of T_{g2} for CPEs transmitting from idle state may be set to 0 (because almost no time is needed to switch the DP transceiver from transmission to reception). This case is presented in Figure 9, which also shows the additional symbol (#5) that can be transmitted by line US2 due to savings in turn-around time of the DP. The corresponding value of T_{g1} can be found from equation [1].

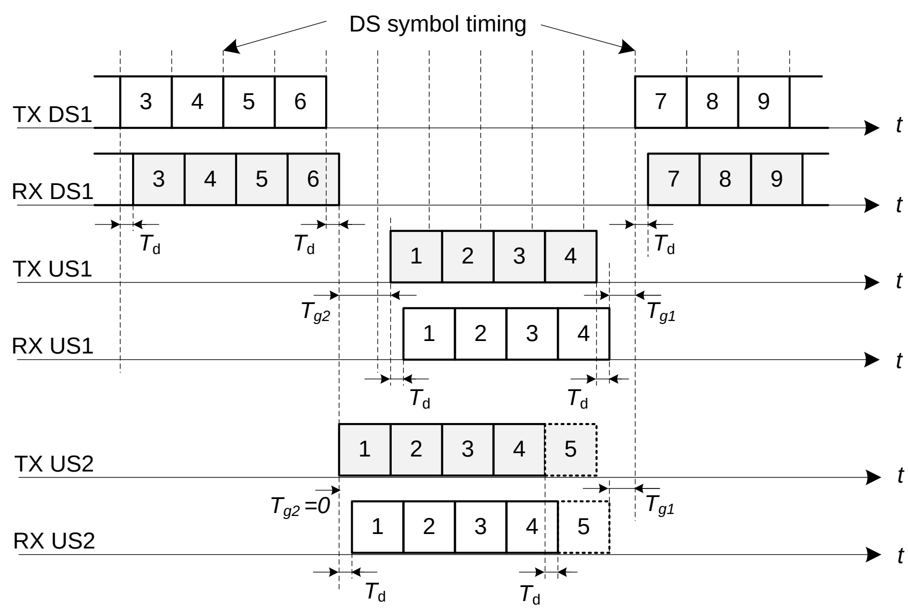

Figure 9 - STDMA transmission for timing at the DP (clear) and CPE (shaded); cases of a full-duplex DP and transmission from a CPE right after reception (US1) and from a CPE in idle state (US2)

2.7 Retransmission

The CPE may request the DP to retransmit data units (DU) received in error if retransmission capability is assigned for a particular service. If a CPE receives one or more DUs in error and retransmission capability for the service these DUs belong to is set, the CPE may send to the DP a retransmission request for these DUs and the DP will retransmit them at the first available transmission opportunity.

The retransmission request message of the CPE is embedded into the first available TS_{US} following the TS_{DS} during which an errored DU was received. If retransmission request is sent in the first symbol of the mentioned TS_{US}, the DP gets more time available to prepare for retransmission. Similarly, the DP may request a CPE to retransmit a DU.

For an example of US/DS transmission allocations presented in Figure 5, the retransmission request on errored reception of DUs transmitted during M1 DS1 data symbols is sent during M3 US1 data symbols. The requested DUs are retransmitted during M6 DS1 data symbols.

2.8 Vectoring

The vectoring arrangements in STDD mode are similar to those used in G.993.5. The proposed transmission format provides symbol synchronization and SS synchronization between transmission lines. Using of pilot sequences on selected tones allows estimation of FEXT coupling between the lines of the vectored group in both upstream and downstream.

Similar arrangements are applicable in case of STDMA if two or more STDMA groups are sourced from a single DP and time overlaps between lines of different groups are foreseen.

3 Summary

1. This paper shall be presented at the G.fast session and relates to the issues 6.4.2 of the G.fast issues list 2012-02-4A-U20.

2. This paper proposes to agree on the following issues:

6.4.2.X (new)	Open	Should the transmission format of G.fast accommodate both synchronized TDD (STDD) and synchronized TDMA (STDMA) modes of operation? NOTE: The STDD (also called P2P) and STDMA (also called P2MP) modes are as described in 11RV-062	11RV-062 2012-02-4A-054
6.4.2.X.1 (new)	Open (27-Feb-12)	Should the transmission format of G.fast comprise of superframes that - superframes follow one another continuously, with no gaps; - each superframe starts from a SyncsSymbol followed by M symbol periods for data/management/control symbols - each superframe is divided into groups of consecutive symbols; each group may be assigned for upstream or downstream transmission; - SyncSymbols shall be always transmitted in the downstream; - SyncSymbols may be transmitted also in the upstream (if configured)?	2012-02-4A-054

6.4.2.X.2 (new)	Open (27-Feb-12)	Should superframes of all lines connected to a DP be aligned in time as follows: - superframes of all lines connected to a DP shall be aligned by downstream SyncSymbols (i.e. downstream SyncSymbols of all lines are aligned); - downstream symbols of all lines shall be aligned; - upstream symbols of all lines shall be aligned?	2012-02-4A-054
6.4.2.X.3 (new)	Open (27-Feb-12)	Should the order of transmission in upstream and downstream for the assigned groups of consecutive symbols (as per Issue 6.4.2.X.2) be determined by the medium access plan (MAP): - MAP includes the schedule of all upstream and downstream transmissions for all lines connected to a DP; - MAP is generated and updated by the DP, and distributed to all CPEs connected to the DP; - both DP and any CPE shall strictly comply with transmission timing defined in the MAP?	2012-02-4A-054
6.4.2.X.3.1 (new)	Open (27-Feb-12)	Should in case of STDD: - downstream transmissions over all lines be aligned in time and upstream transmissions over all lines aligned in time; - the same number of upstream and downstream transmissions be performed during a superframe?	2012-02-4A-054

2. This paper proposes the following open issue:

6.4.2.X.1.1 (new)	Open (27-Feb-12)	What should be the number of symbol periods in a superframe?	2012-02-4A-054

4 References

[1] ADTRAN: "G.fast: On the Synchronous TDMA framing structure**"**. ITU-T SG15 Contribution, COAST-NAI-2011-066, San Diego; November 2011

[2] Lantiq: "Mechanism for managing TDD and S-TDMA framing parameters". Contribution ITU-T SG14/Q4 C-1989, Geneva, Switzerland, December 2011

[3] VDSL Alliance: "VDSL Alliance SDMT draft standard proposal". Contribution T1E1.4/97-332, September 22 1997.

[4] ADTRAN: "Shared Architecture for G.fast". Contribution ITU-T SG15/4 11RV-062, Richmond, Virginia; November 2011