

Agenda item: 8.1.2.2
Source: Qualcomm Incorporated
Title: Summary of [86-19] Discussion on Slot Structure Use Cases
Document for: Discussion/Decision

Description

From RAN1 #86 meeting, there was a discussion captured in R1-168489 on “Use Cases/Scenarios for Slot Structure Discussion”, to provide more details on the specific parameters intended for use with respect to the agreements related to slot structure, as given below.

Agreements:

- › Followings are considered as starting points of NR frame structure at least within the CP overhead
 - Subframe
 - › Already agreed upon
 - › Assume $x=14$ in the reference numerology for subframe definition (for normal CP)
 - › FFS: $y=x$ and/or $y=x/2$ and/or y is signalled
 - Slot
 - › Slot of duration y OFDM symbols in the numerology used for transmission
 - › An integer number of slots fit within one subframe duration (at least for subcarrier spacing is larger than or equal the reference numerology)
 - › The structure allows for ctrl at the beginning only
 - › The structure allows for ctrl at the end only
 - › The structure allows for ctrl at the end and at the beginning
 - › Other structure is not precluded
 - › One possible scheduling unit
 - Mini-slot
 - › Should at least support transmission shorter than y OFDM symbols in the numerology used for transmission
 - › May contain ctrl at the beginning and/or ctrl at the end
 - › The smallest mini-slot is the smallest possible scheduling unit (FFS: smallest number of symbols)
 - Note: the names are for the purpose of discussion. Whether some terms can be merged or not is FFS
 - FFS whether NR frame structure needs to support both slot and mini-slot or these can be merged

To extend the discussion in R1-168489, the following was agreed for further inputs on use cases.

Email discussion where proponents provide further input on use cases with completion by 15th Sep.

Below are some additional requested details to facilitate this discussion. As before with R1-168489, please provide all lengths in terms of symbols for each intended SCS. Absolute times (e.g, ms or us) may also be given for further clarification. Note that this discussion should keep in mind aspects for FDD, TDD, and unlicensed operation, since it addresses frame structure in general. Finally, to be consistent with R1-168489, the default assumption for the numerologies is NCP unless otherwise indicated in your responses below.

1 Summary of Discussion

The discussion was organized into four basic questions (with detailed sub-questions and feedback provided at the end of this document):

1. What transmission durations should be supported and for which numerologies (e.g. 15 kHz subcarrier spacing)?
2. How often can DL control appear? UL control?
3. How often can user be scheduled?
4. How often may gaps appear w/in transmission duration?

1.1 Slot Lengths and Subcarrier Spacings

From the responses, it appeared that almost all companies could describe their transmission durations in terms of slots. In many cases, this was described as a fundamental unit of transmission containing downlink control at the beginning and opportunity for uplink control at the end.

The slot lengths among companies seemed almost evenly divided between 7 and 14 symbols, with a slight majority opting for 14 slots. It was widely accepted that slot aggregation should be supported e.g., through dynamic L1 indication of semi-static RRC signaling. For cases where companies sought 14, it was clear from some proposals that the intention was to have more flexibility as well as less signaling overhead by exploiting more symbols. It is not clear 7-symbol slot aggregation would accomplish the same, although this ultimately would depend on the specification of structures and how they would be configured.

With regard to subcarrier spacing (SCS), a majority of companies did not supply specific target numerologies, however for the remaining companies the range of values was from 15kHz to 480kHz with factor of two scaling between numerologies. After 15kHz, there seemed to be more mention of 30kHz and 60kHz in examples, with additional multi-company support at each of the numerologies 120kHz, 240kHz, and 480kHz.

Lastly with regard to slot length in absolute time, it seemed to be understood that the slot length (or transmission duration) not scale continuously with increasing SCS; i.e., for higher SCS, there should be either more symbols per slot, or a minimum number of slots aggregated per transmission. This was partly to acknowledge that physical and device limitations will prevent addressing such small durations as the SCS scales much higher. A common minimum among companies was 0.125ms, with some even considering as low as 62.5us.

Given such observations, the following proposals can be brought for discussion.

Proposal 1: *For the slot duration y , at least the following should be supported*

- *Configurations supporting slot $\gamma = 7$ and 14 symbols*

Proposal 2: *For transmission durations of EMBB, at least the following should be supported*

- *Ability to define transmission duration through the aggregation of slots*
 - *Configuration may be through semi-static RRC signaling or dynamic L1 indication*
 - *FFS: if any aspects of aggregation or related control should be captured in specification*
- *Ability to configure the minimum transmission duration of more than 14 symbols at higher SCS*
 - *FFS: how to define the minimum*
 - *Option 1. Minimum value of SCS (e.g., 120kHz needs 28 symbols)*
 - *Option 2. Minimum transmission duration of [0.125ms]*
 - *Option 1: Configuration of γ to be larger than 14*
 - *Option 2: Aggregation of slots to achieve*

1.2 Mini-Slots

Due to the structure of URLLC transmissions envisioned by many companies, a notion of mini-slot seems necessary for the specification. Several important arguments related to this are as follows:

- Fewer symbols at the nominal CP as EMBB would be desirable to handle the delay spread
- The reference signal and time domain structure when there are fewer symbols may be significantly different some those defined for slots (in which case, it is advantageous to use a different term altogether).
- Slots and mini-slots may have DL control at the beginning, but mini-slots may not include uplink control at the end while slots may be configured to always include uplink control at the end

Many companies allowed for general notions of mini-slot duration to be anything less than nominal slot length, though suggested some aspect for downselection. One important aspect for consideration which may help downselection is the timeline necessary for mini-slot control monitoring on the downlink.

Proposal 3: *The NR frame structure should support both slots and mini-slots.*

- *FFS: Timeline granularity for monitoring control of the mini-slot*

1.3 Control and Scheduling Intervals

From the discussion, it was widely understood that the by the definition of the slot agreed above, the scheduling granularity would follow the slot duration (or minimum aggregation of slots). Therefore, we have that the typical scheduling intervals intended by companies follows the slot durations and numerologies given in the previous subsection. Specifically, we have the following.

Proposal 4: *The NR frame structure should at least support the following*

- *Periodicities for downlink and uplink control equal to 250us, 500us, and 1m*
- *Longer intervals or aperiodicity resulting from e.g., semistatic or dynamic slot aggregation*

1.4 Subframe duration

Given the numerologies and slot duration use cases specified by many of the companies, it seems more agreeable to have the following subframe definition update.

Proposal 5: Define a subframe duration as 1 ms with a reference numerology 14-symbols at 15 kHz SCS.

2 Questions and Responses

2.1 What transmission durations should be supported and for which numerologies (e.g. 15 kHz subcarrier spacing)?

- This is mostly a re-statement of R1-168489, “Use Cases/Scenarios for Slot Structure Discussion” to keep this document complete. Please feel free to provide any updates or clarifications.
- Please also indicate whether this is related to “slot” or “mini-slot” definition as agreed above, or if there is another relationship for this duration is defined, e.g., length of time to transmit a TB.

Company	Response																					
Qualcom m	EMBB: 14 for 15kHz, 30kHz (1 and 0.5ms), 28 for 120kHz (0.25ms). For subsequent questions, we refer to such duration as “slot” based on agreement above. URLLC: less than 7 symbols for 30kHz and 60kHz. This duration might be considered a “mini-slot”.																					
NTT DOCOMO	For eMBB, 7 and 14 should be possible for SCS narrower than a certain value (FFS: e.g., 120kHz), since both transmission durations of 7-symbol and 14-symbol have different merits (latency reduction vs overhead reduction). For SCS wider than the value, multiple of 7 and/or 14 (e.g., 28 or 56) would be more feasible, since the absolute transmission duration in ms is already short enough for the wider SCS. Furthermore, such wider SCS ($\geq 120\text{kHz}$) is mainly for millimeter wave communications; due to limited coverage distance and/or limited coverage area of the scenario, the number of active UEs within a beam/cell will not be large and therefore, extremely shorter transmission duration (e.g., 31.25us with SCS = 240kHz) that enables finer granularity of TDM for UEs would be less motivated. A potential set of transmission durations based on the above discussion is described in the following table as a set of example. In this example, minimum transmission duration for eMBB usual use-case is assumed to be 0.25ms / 0.125ms. <table><tr><th>SCS</th><th>15kHz</th><th>30kHz</th><th>60kHz</th><th>120kHz</th><th>240kHz</th><th>480kHz</th></tr><tr><td>No. of symbols per Tx duration</td><td>14/7</td><td>14/7</td><td>14/7</td><td>28/14</td><td>56/28</td><td>112/56</td></tr><tr><td>Tx duration in ms (depends on ref. num., this may not be exact)</td><td>1ms/ 0.5ms</td><td>0.5ms/ 0.25ms</td><td>0.25ms/ 0.125ms</td><td>0.25ms/ 0.125ms</td><td>0.25ms/ 0.125ms</td><td>0.25ms/ 0.125ms</td></tr></table> There are two ways to link between the above transmission durations and slot. One way is to define slot length in the number of symbols irrespective of the transmission duration differences among SCSs. For example, slot length can be fixed to 7 symbols or 14 symbols, irrespective of the SCS value. In this case, transmission duration shorter than the slot length should be realized by using mini-slot, and transmission duration longer than the slot length	SCS	15kHz	30kHz	60kHz	120kHz	240kHz	480kHz	No. of symbols per Tx duration	14/7	14/7	14/7	28/14	56/28	112/56	Tx duration in ms (depends on ref. num., this may not be exact)	1ms/ 0.5ms	0.5ms/ 0.25ms	0.25ms/ 0.125ms	0.25ms/ 0.125ms	0.25ms/ 0.125ms	0.25ms/ 0.125ms
SCS	15kHz	30kHz	60kHz	120kHz	240kHz	480kHz																
No. of symbols per Tx duration	14/7	14/7	14/7	28/14	56/28	112/56																
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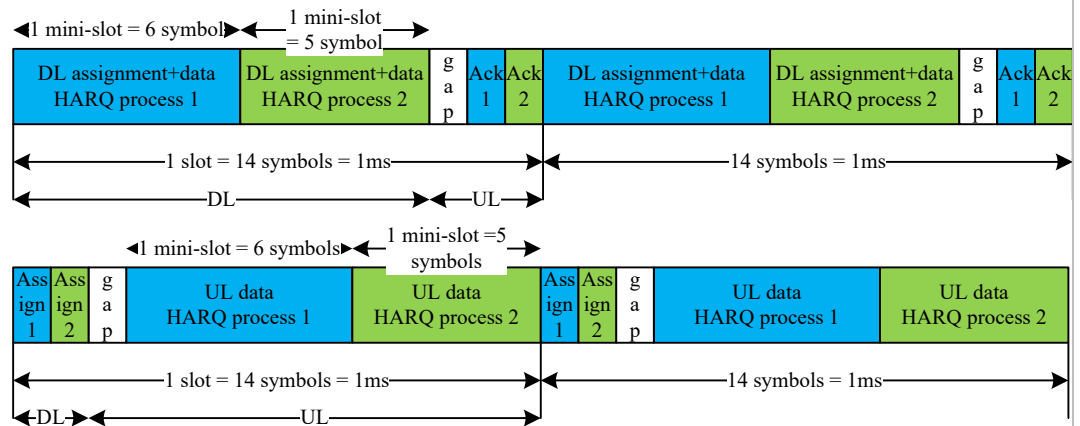
	should be realized by using multiple-slot aggregation. Another way is to define multiple slot lengths in the number of symbols that could be different among SCSs or could be variable. For eMBB, in addition to the above, transmission durations for latency reduction should also be supported. In LTE, 2-symbol transmission duration (a.k.a short-TTI) will be introduced in Rel.15. From the viewpoint of NR/LTE dual connectivity base station, traffic control would become more complicated if peak data rate is NR > LTE (due to wider bandwidth in NR) while latency performance is NR < LTE (due to short-TTI support). Therefore, shorter transmission duration should be supported for NR eMBB for the purposes of latency reduction. There are two possible solutions for transmission duration shortening for NR: (1) by using wider SCS to reduce symbol length, and (2) by reducing the number of symbols. The first one enables, e.g., 0.125ms transmission duration by using wider SCS such as 60kHz/120kHz. On the other hand, the latter one would be beneficial especially for lower carrier frequency. Therefore, also for NR eMBB, shorter transmission duration using smaller number of symbols, e.g., 2-symbol (and/or 1-symbol) transmission duration, should be supported. This shorter transmission duration in the number of symbols could be handled as mini-slot. For URLLC, same discussion applies as for eMBB latency reduction. Shorter transmission duration by reducing the number of symbols is useful. Such transmission duration with smaller number of symbols could be handled as mini-slot. In the above discussion, both eMBB latency reduction and URLLC consider to use mini-slot. RAN1 should strive for designing common framework for these two use-cases.
ZTE	7/14/28 symbols should be supported for transmission duration and they should tie with the definition of slot for numerologies based on the NCP-family. Other number of symbols are not excluded. (For example, the number of symbols is allowed to be slightly adjusted, if necessary). For 7-symbol slot, it might be more useful for URLLC. However, it will not be restricted to certain services. In addition, 2-symbol transmission duration can be introduced (For FDD). If 2-symbol transmission duration can be different structure as slot, then it can be defined as mini-slot. The starting symbol of a slot may not be necessarily aligned with subframe.
Ericsson	A slot is the basic scheduling unit for most use cases (e.g. EMBB). Slot aggregation is possible to reduce control signaling overhead, e.g. a single control message can schedule two or more slots in a row to the same UE. The basic slot length is 7 symbols (0.5 ms @ 15 kHz, 0.25 ms @ 30 kHz, etc). For very high subcarrier spacings it may make sense to consider slots with a larger number of OFDM symbols. For latency-critical data (and for unlicensed operation) a mini-slot can be used which is of length < 7 OFDM symbols.
Panasonic	Our usage is "within a slot, at maximum one Tx/Rx switching " and "mini-slot as the minimum TTI length". Therefore, how often Tx/Rx switching occurs determines slot length. TTI length determines mini-slot length. For 15 kHz subcarrier spacing, we see the need of similar DL/UL switching behaviour over 1ms with special subframe for the case that the neighbor cells are LTE TDD. In addition, one symbol granularity is large. Therefore, at least 14 symbol slot length should be supported. For 60 kHz or

higher, TTI corresponding to 0.125 ms would be sufficient as the minimum granularity. Currently UE's RF transition time of on/off and power change is the order of 20 to 40 usec. Although we should reduce such transition time in NR, these numbers would not be scale well. Therefore, our view is 0.125 ms (125 usec) would be sufficient minimum granularity. Further elaboration is described below.

For 15 kHz subcarrier spacing:

- eMBB:

- Slot length is 14 symbols (1ms). Mini-slot length can be 2, 5, 6 symbols.



- We are also ok to support slot length 7 symbols (0.5ms) in addition. This is for latency reduction purpose if necessary.

- URLLC:

- Same as EMBB. Mini-slot with FDD is used to satisfy latency requirement if 15 kHz subcarrier spacing is used. Or to use higher subcarrier spacing described below.

- mMTC:

- Same as EMBB.

For 30 kHz subcarrier spacing:

We are FFS whether this subcarrier spacing is supported or not. If supported, our view is same as 15 kHz subcarrier spacing should be fine. It means slot length is 14 symbols of 0.5ms.

For 60 kHz or higher subcarrier spacing:

Slot length for eMBB, URLLC and mMTC corresponds to 0.125ms. It means 14 symbols in 120 kHz. 7 symbols in 60 kHz subcarrier spacing (if supported). 28 symbols in 240 kHz (if supported). 56 symbols in 480 kHz (if supported)

No need to use mini-slot in these subcarrier spacing. We are also ok to support mini-slot length corresponding roughly half of one downlink part and half of one uplink part. This allows similar to 15 kHz behaviour.

Fujitsu

This response is based on the understanding that “transmission duration” is a time interval that from a UE perspective can be configured to contain at least one instance of a control channel

and at least one transport block. The preference is to merge the definitions of slot and mini slot, so here “transmission duration” covers both.

Considering forwards compatibility, the following should be supported (or at least not precluded) by the frame structure framework:

Sub-carrier spacing	Nominal symbol duration (including normal CP) (μs)	Nominal normal CP duration (Note 1) (μs)	Duration of 28 symbols (μs)	Duration of 14 symbols (μs)	Duration of 7 symbols (μs)	Duration of 4 symbols (μs)	Duration of 2 symbols (μs)	Proposed transmission durations to be supported for FDD (symbols)
15kHz	71.43	4.76	2000	1000	500	285.71	142.86	7, 4, 2, 1
30kHz	35.71	2.38	1000	500	250	142.86	71.43	14, 7, 4, 2
60kHz	17.86	1.19	500	250	125	71.43	35.71	28, 14, 7, 4
120kHz	8.93	0.60	250	125	62.5	35.71	17.86	28, 14, 7
240kHz	4.46	0.30	125	62.5	31.25	17.86	8.93	28, 14
480kHz	2.23	0.15	62.5	31.25	15.625	8.93	4.46	28

Note 1: The CP length stated here assumes equal CPs for all symbols in a slot/subframe, which would not be the case in practice when following LTE timings.

For 15kHz sub-carrier spacing the proposed transmission durations of 7, 4, and 2 symbols match those under discussion for short TTI lengths in LTE. A transmission duration of 1 symbol is proposed to allow NR to exceed LTE capabilities in terms of latency and also allow the possibility for more convenient multiplexing with transmissions with shorter symbol durations.

Note that the shortest transmission durations to be supported would be around 60μs.

Suitable transmission durations for eMBB and URLLC use-cases are as follows:-

Sub-carrier spacing	Suitable transmission durations for FDD eMBB use case (self-contained transmission is not assumed) (symbols)	Suitable transmission durations for FDD URLLC use case (without self-contained transmission) (symbols)	Suitable transmission durations for FDD URLLC use case (with self-contained transmission) (symbols)	Suitable transmission durations for TDD eMBB and URLLC use cases (assuming 1 gap for Tx/Rx switching) (symbols)
15kHz	7, 4, 2	4, 2, 1	7, 4	7, 4
30kHz	14, 7, 4	7, 4, 2	14, 7, 4	14, 7, 4
60kHz	28, 14, 7	14, 7, 4	28, 14, 7, 4	28, 14, 7, 4
120kHz	28, 14	28, 14, 7	28, 14, 7	28, 14, 7
240kHz	28	28, 14	28, 14	28, 14
480kHz	28	28	28	28

Note: That eMBB and URLLC services may be multiplexed on the same carrier, which would be simplified if the same (or compatible) transmission durations are configured for both

At least for 15kHz sub-carrier spacing, signals transmitted over longer durations than 7 symbols should also be supported (e.g .for mMTC or eMBB TDD), either explicitly by defining longer slots, or by concatenation of slots.

The set of supported transmission durations for sub-carrier spacings less than 15kHz could be based on the set {7,4,2,1} but with some possible down selection.

In general it seems unnecessary to support very short “transmission durations” for TDD

MediaTek

eMBB: 7 OFDM symbols (0.5ms or 0.125ms) for subcarrier spacing of 15KHz and 60KHz; 28 OFDM symbols (0.125ms) for subcarrier spacing of 240KHz

	URLLC: Less than 7 OFDM symbols (e.g. 3 or 4 OFDM symbols) for subcarrier spacing of 15KHz; 7 OFDM symbols (0.125ms) for subcarrier spacing of 60KHz; 28 OFDM symbols (0.125ms) for subcarrier spacing of 240KHz According to our evaluation, it requires 0.5ms slot length to meet the latency requirements for eMBB (4ms for DL/UL) so we think 7 OFDM symbol slot length should be supported for subcarrier spacing of 15KHz. To support URLLC with subcarrier spacing of 15KHz, smaller slot length is needed. According to our evaluation, it requires 0.125ms slot length to meet the latency requirements for both eMBB (4ms for DL/UL) & URLLC (0.5ms for DL/UL) so we think 7/28 OFDM symbol slot length should be supported for subcarrier spacing of 60KHz/240KHz and no other slot length is needed for URLLC. 0.125ms should be the smallest slot length for all supported subcarrier spacings because it allows sufficient UE processing time for PHY control processing and there are no benefits on meeting latency requirements to scale down the slot length with increasing subcarrier spacing.																					
Mitsubishi Electric	If the number of symbols per subframe/slot/mini-slot is discussed in this email discussion, numerologies based on the NCP-family should be assumed. Since multiple CP lengths can be defined, different number of symbols from the ones that are mentioned in this email discussion should not be excluded.																					
Nokia	A ‘slot’ of 7 symbols is the basic scheduling unit. We could either have a (potentially dynamically) configurable slot duration of at least 7, 14, 28 symbols, or perhaps more preferably concatenate multiple fixed duration 7-symbol slots to achieve longer transmission durations. The 7-symbol minimum scheduling unit should be supported at least up to 60 kHz. In principle the specification should enable using this 7-symbol slot up to any numerology adopted, and an additional restriction of what is the minimum transmission duration so that e.g. with 240 kHz SCS there would always be 4 slots concatenated to keep the max UL/DL switching rate the same as with 60 kHz. Possible applicability table of slot concatenation in a given numerology. Note that this should not be read as Nokia position on supported numerologies, but rather demonstrate scalability <table><tr><td>SCS</td><td>15kHz</td><td>30kHz</td><td>60kHz</td><td>120kHz</td><td>240kHz</td><td>480kHz</td></tr><tr><td>Slot duration</td><td>7</td><td>7</td><td>7</td><td>7</td><td>7</td><td>7</td></tr><tr><td>Min scheduling unit configuration</td><td>1 slot</td><td>1 slot</td><td>1 slot</td><td>2 slots</td><td>4 slots</td><td>8 slots</td></tr></table> For latency-critical transmissions, a shorter ‘mini-slot’ of (somewhat) flexible length and (somewhat) flexible starting position in relation to ‘slot’ should be considered.	SCS	15kHz	30kHz	60kHz	120kHz	240kHz	480kHz	Slot duration	7	7	7	7	7	7	Min scheduling unit configuration	1 slot	1 slot	1 slot	2 slots	4 slots	8 slots
SCS	15kHz	30kHz	60kHz	120kHz	240kHz	480kHz																
Slot duration	7	7	7	7	7	7																
Min scheduling unit configuration	1 slot	1 slot	1 slot	2 slots	4 slots	8 slots																
Samsung	a) Only one of ‘slot’ or ‘mini-slot’ needs to be defined – ‘slot’ is assumed in the following. b) Slot duration is more a matter of choice rather than a fundamental design issue. One option is to define the slot duration to correspond to the minimum possible number of symbols for a given SC spacing (e.g. 2 symbols for 15 KHz SC spacing) and increase the number of symbols by DCI as needed for scheduling (e.g. to 2/7/14/28 symbols for 15 KHz SC spacing). Another option is to define the slot																					

	duration to correspond to a reference number of symbols for a given SC spacing (e.g. 7 symbols for 15 KHz SC spacing) and adjust the number of symbols by DCI as needed for scheduling (e.g. to 2/7/14/28 symbols for 15 KHz SC spacing). A combination of DCI and RRC is preferable. For example, for 15 KHz SC spacing, the slot duration can be RRC configured to include either 2/7/14 symbols - DCI can then adjust the number of symbols (e.g. to one of 2/7/14/28). For very large SC spacings, a number of symbols per slot larger than 14 can be supported. c) It should not be precluded to have different numerologies (slot duration, CP length, etc.) for DL and UL. d) There is no need to define ‘transmission duration of a transport block’ – this is similar to LTE where the transmission duration of a TB can be less than 1 subframe but this is not explicitly defined.
Huawei	Docomo’s and Ericsson’s responses are a good starting point for defining slots, with a slot defined as 7 or 14 OFDM symbols (assuming normal CP type). We prefer 7 symbols as a common basic slot structure to define time-domain relations of DL/UL control/data channels and reference signals. We consider that 7 symbols is a typical use case for eMBB considering NR carrier bandwidths would typically be 20 MHz or larger, compared with one subframe of LTE 10 MHz typical bandwidth. For larger subcarrier spacings eMBB scheduling durations longer than 7 symbols are achieved by aggregating slots. If both 7 and 14 symbols are supported for a slot then we should strive to define a common time-domain structure (e.g. scaled). From a specification perspective this should be a common structure for all subcarrier spacings (with possibly some exception at very large subcarrier spacings to avoid a large overhead due to beam switching time). Some slight adaptation is required when a larger cyclic prefix is configured since the number of symbols per slot will be smaller (e.g. 6); this difference of one symbol can be absorbed in the duration of the data channels so it should not affect the basic structure. Some flexibility for scheduling starting symbol and duration would be useful for transmission in unlicensed spectrum after LBT. Some scalable slot or mini-slot could be defined for this purpose. If the mini-slot duration is only a few symbols shorter than a slot then the same time-domain structure as for a slot could be reused. If extremely short durations (e.g. 2 OFDM symbols) are defined for a mini-slot then it is unlikely that a mini-slot could be defined using the time-domain structure of a slot. Therefore we think it makes sense to keep a separate definition of slot and mini-slot in this discussion.
Sony	For non-standalone case, the number of symbols should be selected to ensure alignment with LTE. The choice of number of symbols should take into account the use of multiple CP lengths per subcarrier spacing. For standalone case, such alignment with LTE is not necessary and hence there should be more flexibility in the choice of transmission durations. The exact number of symbols per slot/subframe/subcarrier spacing does not need to be decided during SI and can be decided in the WI phase.
CATT	Both slot and mini-slot are needed for eMBB, URLLC and mMTC services. Slot is one possible scheduling unit. Slot would be used as the unit for UE to monitor DL control channel for DL or UL grant. Mini-slot is the minimum scheduling unit. A UE could be scheduled one or multiple

	mini-slots of DL or/and UL transmission within a slot. The scheduler should have the flexibility to schedule number of mini-slot for a UE within the slot. Our view is that slot is 7 OFDM symbols for all subcarrier spacing for both eMBB and URLLC. Slot is multiple of 7 OFDM symbols for mMTC. Mini-slot is 1 OFDM symbols and the minimum scheduling unit for all subcarrier spacing.																												
LG	For eMBB, 14 OS or multiple of 14 OS can be used for scheduling unit, and if necessary 14 OS can be defined as a slot. However, our preference is to define only subframe and “mini-slot” where mini-slot can be used for UE-specific scheduling unit and subframe can be used for group-specific or cell-specific scheduling unit. For eMBB, one of mini-slot size can be 14 OS. Finer scheduling unit can be also considered for eMBB where mini-slot(s) size can be multiple of 2 OS. For URLLC, mini-slot can be smaller than 14 OS, at least for 15, 30 and 60 kHz. To support potentially lower user-plane latency than 0.5msec, it is also considerable to adopt or allow mini-slot size smaller than 14 OS even in higher subcarrier spacings. For mini-slot size for URLLC, we propose it can be multiple of 2 (e.g., 2, 4, 8). Defining 7OS as a slot or mini-slot may lead inefficient multiplexing among different numerologies. For example, 7OS 60 kHz URLLC with 15 kHz eMBB requires emptying 2 OS of 15 kHz though only 7 OS is used for URLLC transmission. To overcome the issue, one approach is to use 8 OS 60 kHz URLLC multiplexed with 15 kHz eMBB.																												
MotM	Following the “slot” and “mini slot” discussion from RAN1#86, slot duration of 7 symbols should be supported for all numerologies. At least for 15 and 30kHz sub-carrier spacing, additional slot duration of 1 or 2 symbols (can be referred to as mini-slot) should also be supported.																												
ETRI	Both slot and mini-slot should be supported as scheduling units. Slot is a default scheduling unit and mini-slot is used only when configured. Our preference is 14 symbol slot length and 2 symbol mini-slot length for all numerologies. For 15kHz, this provides 1ms duration for eMBB and 0.15ms duration for eMBB/URLLC. Although 1ms scheduling interval seems small enough for best-effort services, shorter durations (e.g., 0.5ms and 0.25ms) are still valid by choosing larger subcarrier spacing. The same can be done for URLLC (e.g., 0.125ms slot for 120kHz and 0.075ms mini-slot for 30kHz). Frequency hopping can be defined within a slot if needed. <table><tr><td>SCS</td><td>15kHz</td><td>30kHz</td><td>60kHz</td><td>120kHz</td><td>240kHz</td><td>480kHz</td></tr><tr><td>Slot duration</td><td>14</td><td>14</td><td>14</td><td>14</td><td>14</td><td>14</td></tr><tr><td>Mini-slot duration</td><td>2</td><td>2</td><td>-</td><td>-</td><td>-</td><td>-</td></tr><tr><td>Minimum slot aggregation # for one scheduling opp.</td><td>1 slot</td><td>1 slot</td><td>1 slot</td><td>FFS</td><td>FFS</td><td>FFS</td></tr></table>	SCS	15kHz	30kHz	60kHz	120kHz	240kHz	480kHz	Slot duration	14	14	14	14	14	14	Mini-slot duration	2	2	-	-	-	-	Minimum slot aggregation # for one scheduling opp.	1 slot	1 slot	1 slot	FFS	FFS	FFS
SCS	15kHz	30kHz	60kHz	120kHz	240kHz	480kHz																							
Slot duration	14	14	14	14	14	14																							
Mini-slot duration	2	2	-	-	-	-																							
Minimum slot aggregation # for one scheduling opp.	1 slot	1 slot	1 slot	FFS	FFS	FFS																							
Intel	Slots are defined by a fixed number of OFDM symbols regardless of the subcarrier spacing. Our preference for the slot duration is $\gamma=14$ OFDM symbols. Aggregation of slots is supported. This can be done via semi-static RRC signaling or dynamic L1 indication. In addition, default aggregations may be defined depending on the subcarrier spacing, e.g., for large subcarrier spacings, multiple slots may be aggregated by default.																												

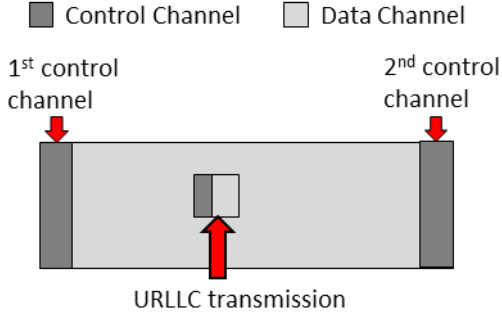
	Potential mini-slot sizes at least include {2,4,7,8,14} OFDM symbols. To be precise, these transmission durations should be supported by the specification and signaling design can determine how exactly the aforementioned mini-slot sizes can be achieved. For NR operation in unlicensed spectrum, the transmission duration could be flexible to match the MCOT.
InterDigital	On the transmission durations that should be supported: - For URLLC, it should be possible to support transmission durations not exceeding 0.2 ms. This represents about 2 symbols at 15 kHz, 4 symbols at 30 kHz for normal CP family - For eMBB, the optimal transmission duration may depend on many factors as evaluated during the latency reduction study. Short durations of the order of 0.2 ms can be beneficial for e.g. short TCP transfers, otherwise a duration of 0.5 ms or 1 ms may be sufficient. On the relationship with slot and mini-slot: - We think it would make sense that the concept of “slot” be associated with “scheduling unit” or “minimum scheduling unit” for a UE. - To achieve a suitable scheduling unit for a UE it should be possible that the duration of a “slot” in terms of number of symbols (and CP overhead), be configurable for each subcarrier spacing value and direction (UL/DL). - With a configurable slot duration the need for additionally defining a mini-slot is uncertain. - Use of different numerologies in DL and UL should be supported.

2.2 How often can DL control appear? UL control?

- How is this related to the transmission duration in previous question (if related)?

Company	Response
Qualcomm	EMBB: DL control can at least occur at slot beginning, and UL control can occur at slot end.
NTT DOCOMO	For eMBB transmission durations having 7 symbols or more, DL-only, UL-only, and bi-directional (i.e., DL-part + UL-part) types, should be enabled. These types of transmission duration should correspond to one slot or multiple slots (depends on the slot definition). If the transmission duration corresponds to one slot, DL and UL controls should appear once per slot. If the transmission duration corresponds to multiple slots, there are two alternatives: (1) DL and/or UL controls may appear once per slot while data spans over multiple slots, and (2) DL and UL controls may appear once per transmission duration (i.e., once per multiple slots). First alternative has better flexibility while increases signalling overhead and/or complexity. For eMBB/URLLC transmission duration having 2 symbols (or 1 symbol), DL-only and UL-only should be enabled (i.e., no bi-directional type would be necessary). DL and UL controls should be able to appear once per DL-only and UL-only mini-slot, respectively.

ZTE	DL control can be transmitted from beginning of slot. UL control can be transmitted toward end of slot as default. However, it can be also configured to middle of slot in order to reduce feedback latency and Gap overhead.
Ericsson	DL control can occur at the beginning of a downlink slot. UL control can occur at the end of an uplink slot. DL control can occur at the beginning of a downlink mini-slot. UL control can occur at the end of an uplink mini-slot (FFS).
Panasonic	Every mini-slot has the possibility of DL control for eMBB, URLLC, mMTC. There can be restriction on the possible mini-slot by DRX or some other mechanism. If there is no control, the time frequency resource may be used for the data assigned by previous control. Every mini-slot has the possibility of UL control for eMBB, URLLC, mMTC. There can be restriction on the possible mini-slot by some mechanism. Multiple mini-slot/slot usage of DL control or UL control are supported for coverage enhancements.
	From UE perspective (for any use case, and assuming “transmission duration” and “slot” are equivalent): • DL control can appear once per transmission duration • UL control can appear once per transmission duration • A transmission duration may not necessarily contain any control, or resources allocated for control (e.g. if slots can be concatenated)
MediaTek	eMBB: DL control channel locates at the beginning of a slot; UL control channel locates at the end of a slot. The size of DL control channel can be 0/1/2 OFDM symbols; The size of UL control channel should at least support 1 OFDM symbol and FFS other configurations. URLLC: DL control channel also locates at the beginning of a mini-slot if there is.
Nokia	‘Slot’ • DL control may occur at the beginning of a slot, but not necessarily in every slot • UL control may occur at the end of a slot, but does not need to be there always ‘Mini-slot’ • DL control may occur at the beginning of a mini-slot, but not necessarily in every slot • UL control may occur at the end of a mini-slot, FFS
Samsung	a) DL/UL control appears at most once per slot. b) A slot may or may not contain DL control or UL control. c) When a slot contains DL control, at least location in the beginning of the slot is supported (as for LTE PDCCH). Location over the entire slot should also be supported (as for LTE EPDCCH or MPDCCH). d) When a slot contains UL control, at least locations at the end of the slot (for latency) and over the entire slot (for coverage) need to be supported. FFS for additional locations.
Huawei	Slot structure should support DL-only, UL-only, and bi-directional (DL-part + gap + UL-part) types. DL control can occur at the beginning of a slot, it is expected that typical UEs will monitor DL control at least at slot boundaries. UL control can occur at the end of a slot. For unlicensed spectrum it may be useful to allow DL control signaling not at the slot boundary. If mini-slots are supported then DL control may have to be allowed in a mini-slot. It needs further study whether

	UL control needs to happen in a mini-slot or if it is sufficient to just have uplink at the end of a slot.
Sony	It would be beneficial to have two DL control channels, one at the beginning of the slot and another at the end of the slot. This is useful for multiplexing of eMBB with URLLC where the second control channel can be used to provide information for “repairing” the eMBB if it was punctured by URLLC. 
CATT	DL control channel should be flexibly located at the DL transmission part of a slot. DL control channel could be in the first DL mini-slot or distributed to one or more DL mini-slots within a slot for potential low latency transmission. Multi and cross mini-slot scheduling should be supported to optimize the radio resource for minimizing the control overhead. The DL control channel could appear in every slot. However, the network could configure a time interval large than a lot for UE to monitor the DL control channel. UL control channel should be flexibly located at the UL transmission part of a slot. UL control channel could be any mini-slot configured by the network. The network configures the periodicity of UL control channel.
LG	DL control can be placed in each UE-specific scheduling unit which can be one or multiple of mini-slot or slot. DL control can be also placed in group-specific or cell-specific scheduling unit. UL control can be placed either by scheduling or semi-static configuration. There can be a gap between UL control and end of subframe/slot to allow fast retransmission.
MotM	DL control can appear once a slot. If mini-slot is configured, it can appear once a slot, and once a mini-slot. UL control can appear once a slot. If mini-slot is configured, at least for FDD, it can appear once a slot, and once a mini-slot.
ETRI	Share the same view as Ericsson and Nokia.
Intel	DL control can be transmitted at the beginning of a slot and/or the beginning of a mini-slot. Some slots and mini-slots may not contain any DL control. UL control can be transmitted at the end of a slot and/or mini-slot or at the beginning of an uplink region. Some slots and mini-slots may not contain any UL control.

InterDigital	DL control should be located at least at the beginning of a downlink slot (and mini-slot, if defined) UL control should be located at least at the end of an uplink slot (and mini-slot, if defined) The possibility for additional UL control at the beginning of an uplink slot to support scheduling request or scheduling assignment (e.g. for sidelink) should be considered.
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2.3 How often can user be scheduled?

- What is smallest possible scheduled duration?
- What is the relationship between scheduling unit/duration and subframe/slot/mini-slot (if related)?

Company	Response
Qualcomm	EMBB: scheduling may be once per slot. The smallest duration of the scheduled resource may be smaller than a slot (this could be referred to as a “mini-slot”, with the assumption of an integer number of mini-slots per slot).
NTT DOCOMO	Scheduling is per DL control. Therefore, slot-level scheduling should be carried out per slot or per multiple slots (depending on definition of slot), and mini-slot-level scheduling should be carried out per mini-slot.
ZTE	Scheduling duration should be same as transmission duration. That is: if mini-slot is introduced, the scheduling duration can be as small as mini-slot. The subframe defined in RAN1#86 is actually base on certain numerology, which will give a absolute timing reference for a UE(at least). The slot or mini-slot, whatever the transmission numerology is, will be count by number of symbols and should follow the agreement about symbol alignment.
Ericsson	Once per slot (typical way of operating eMBB in licensed spectrum) or once per mini-slot (for latency-critical transmissions).
Panasonic	Scheduling is per mini-slot.
Fujitsu	From a UE perspective, DL scheduling is once per transmission duration. The duration of the scheduled resource may be smaller than the transmission duration (e.g. for “self-contained” operation or TDD). The duration of the scheduled resource might be larger than the transmission duration (e.g. if slots can be concatenated).
MediaTek	eMBB: The minimal scheduling duration should be 1 slot but it should allow multi-slot scheduling, e.g. up to 4 or 8 slots. URLLC: The minimal scheduling duration should be 1 min-slot if there is.

Nokia	‘Normal’ data is scheduled at most at the rate of once-per-slot, but with slot-concatenation it is possible to reduce the scheduling rate and thus also the UL/DL switching rate and rate at which the DL and UL control are present. ‘Latency critical data’ can be scheduled at a maximum rate of once per mini-slot
Samsung	Scheduling is once per slot and can last (be valid for) one or more slots. The slot duration can be variable as discussed in the first topic.
Huawei	Consistent with the DL control of question 3, scheduling instances can occur at least at slot boundaries. A scheduling duration can be one slot or multiple slots. For unlicensed spectrum it may be useful to allow shorter scheduling durations than one slot, and DL control signaling not at the slot boundary. If mini-slots are supported, at most one scheduling duration is supported in a mini-slot. Aggregation or concatenation of units should be allowed for slot, but needs further study for mini-slots.
Sony	eMBB: Smallest scheduling duration is a slot. URLLC: Smallest scheduling duration is a mini-slot or smaller (commensurate with URLLC latency requirement)
CATT	UE could be scheduled every mini-slot. If more than one mini-slot is scheduled for a UE, multiple mini-slot bundling for a single TTI should be supported to minimize the control overhead.
LG	Scheduling unit is one or multiple of mini-slot or slot, and configurable to each UE.
MotM	User can be scheduled once per slot. If mini-slot is configured, once per slot, and once per mini-slot.
ETRI	A smallest scheduling duration is a mini-slot when supported, while it is a slot when the mini-slot is not supported for both eMBB and URLLC. Scheduling unit could be one slot, multiple slots, or one mini-slot. FFS for multiple mini-slots as a scheduling unit.
Intel	The smallest possible scheduled duration is the smallest mini-slot. Other scheduling units/durations are defined in “units” of slots and mini-slots. At least for eMBB, a slot (or an aggregation thereof) can be considered a typical scheduling unit/duration.
InterDigital	At most once per slot (or mini-slot).

2.4 How often may gaps appear w/in transmission duration?

- How much overhead may be incurred?

Company	Response
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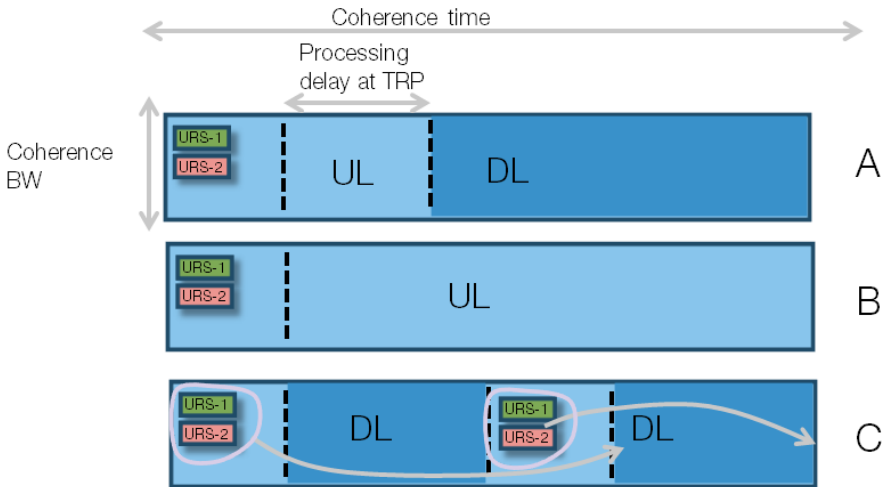
Qualcomm	EMBB: Multiple gaps may appear within a slot, e.g., for Tx/Rx switching or additional forward compatibility. The overall gap overhead would be in terms of symbols, and design should target minimizing overhead per slot.														
NTT DOCOMO	For slot-level scheduling, up to one gap per transmission duration. For mini-slot-level scheduling, more than one gap may appear within a slot duration, depending on combination of mini-slots.														
ZTE	For TDD, Gap should be in number of symbols. Since the overhead is major consideration, we think we can start from 1 gap. Note that the switching for UL/DL can follow the LTE way, which is not explicitly introduced. We can discuss the need for multiple gaps in case we have many symbols in one slot.														
Ericsson	The typical case is at most one DL-to-UL switch in a slot (and one UL-to-DL switch at the end of the slot) but more switch points may occur e.g. is a mini-slot preempts an ongoing slot transmission.														
Panasonic	Gap for Tx/Rx switching is once per slot. Gap for forward compatibility can be more than once per slot but FFS.														
Fujitsu	We propose that slots (corresponding to the “transmission duration” under discussion) are defined independently for transmission and reception (i.e. for UL and DL, respectively, at the UE). This allows the same frame structure framework to be applied for FDD, TDD, half-duplex, sidelink and unlicensed operation. This approach is also compatible with allowing different numerologies to be used in UL and DL. The timings of the transmission and reception slots can be offset (e.g. to allow for timing advance). For TDD, the UE can be configured with a DL slot and an UL slot such that the timing and durations of periods for transmission and reception allow for a gap (or possibly gaps) for Tx/Rx switching. For example, consider the case of 15kHz sub-carrier spacing and 7 symbol slots configured for both transmission and reception at the UE. In the reception slot the first three symbols could be used for receiving DL transmission by the gNB. In the transmission slot the last three symbols could be for UL transmission by the UE, with timing advance applied. The unused symbol in the centre provides a gap or guard period for Tx/Rx switching. This is illustrated in the following example (which is applicable from the UE perspective for both FDD and TDD):- Reception slot <table><tr><td>Rx</td><td>Rx</td><td>Rx</td><td></td><td></td><td></td><td></td></tr></table> Gap Transmission slot <table><tr><td></td><td></td><td></td><td></td><td>Tx</td><td>Tx</td><td>Tx</td></tr></table> Considering the number of gaps, there are a couple of possibilities:- • <u>Only one gap per transmission duration</u> (i.e. a slot contains one set of contiguous symbols used for either transmission or reception), as shown above. The gap overhead would typically be one symbol per slot. For a given Tx/Rx switching frequency the	Rx	Rx	Rx									Tx	Tx	Tx
Rx	Rx	Rx													
				Tx	Tx	Tx									

	proportion of gap overhead can be reduced by choosing a shorter symbol duration for at least one transmission direction (i.e. more symbols per slot). FFS: <u>Multiple Tx gaps are allowed per transmission duration</u>. This implies non-contiguous sets of symbols available for transmission (and reception), and multiple instances of control channels within a slot. In any case this would not be feasible for transmission durations/slots shorter than 5 symbols. A possible example with this approach is shown below, with overhead of 2 symbols per slot. Reception slot <table><tr><td>Rx</td><td>Rx</td><td></td><td></td><td>Rx</td><td></td><td></td></tr><tr><td colspan="4">Gap 1</td><td colspan="3">Gap 2</td></tr></table> Transmission slot <table><tr><td></td><td></td><td></td><td>Tx</td><td></td><td></td><td>Tx</td></tr></table> It should also be noted that optimum efficiency in TDD requires the correct balance of resources to be allocated to UL and DL, as well as consideration of the gap duration and overhead (i.e. dynamic re-configuration of slot contents is necessary).	Rx	Rx			Rx			Gap 1				Gap 2						Tx			Tx
Rx	Rx			Rx																		
Gap 1				Gap 2																		
			Tx			Tx																
MediaTek	eMBB: There is up to one DL/UL switching gap within a slot if the minimal scheduling duration is a slot. URLLC: There is no DL/UL switching gap within a mini-slot even if the minimal scheduling duration is a mini-slot.																					
Nokia	There can be one DL/UL switch within a ‘slot’ + another UL/DL switch at the slot boundary, see example below. D U D U Whether the mini-slot may contain a DL/UL switch is FFS																					
Samsung	Multiple gaps per slot for a given numerology (SC spacing) are not precluded subject to other design considerations.																					
Huawei	For slot-level scheduling up to one gap per slot. Supporting a gap in a mini-slot needs further study.																					
Sony	Multiple gaps should be possible per slot depending on the use case.																					
CATT	Gap should be an UE-specific configuration and could be zero, one , more within transmission duration																					
LG	DL/UL switching gap can be at most once per scheduling unit from a UE perspective. When multiple UEs are scheduled, from the network perspective, there could be multiple DL/UL switching gaps in a subframe.																					
MotM	Not every slot may have a gap for Rx/Tx switch point. FFS: multiple switch points within a slot.																					

ETRI	From UE perspective, up to one gap per slot is sufficient. From system perspective, up to one gap per slot is also preferred but we are ok with multiple gaps if found necessary. It should be further discussed whether the slot/gap configuration is UE-specific or system-specific.
Intel	The number of gaps within a slot depends on the number of necessary DL/UL switching points as well as any other blank resources that may be present. Different use cases may require different number of gaps and configuring more than a single gap within a slot should be supported in NR.
InterDigital	At most one gap for UL/DL switching.

2.5 Any other additional considerations to add?

Company	Response
Ericsson	We propose to define a subframe as 1 ms (i.e. assuming a reference numerology of 15 kHz).
Fujitsu	The current definitions of “slot” and “mini-slot” seem to allow configurations where both structure could have equivalent contents e.g. data with control at the beginning (or end). This overlap suggests that the terms should be merged. Otherwise we could have the situation where a mini-slot is just like a slot, only shorter. In general, flexibility in the time domain could be provided by either • a flexible slot duration (which is our preference), or • a fixed slot duration (in terms of symbols) where the flexibility is provided by dividing a slot into one or more mini-slots. In this case a “slot” seems rather like a “subframe” If a concept like “mini-slot” is retained, it should mean something distinctly different to “slot”, such as “TTI length” as proposed by Panasonic, or indicating the particular symbols occupied by data or control. Then a “slot” would define a time interval and the contents of “mini-slots” would define particular transmissions which are mapped to particular OFDM symbols within a slot. For efficient TDD operation and frequent Tx/Rx switching it should be possible operate with as little as 1 symbol in UL or DL. This 1 symbol should also be available for both control and data (as we pointed out in one of our RAN1 contributions). It should be possible to multiplex control and data within the same symbol, particularly for TDD. For example, if the available bandwidth is 100MHz, then one OFDM symbol at 15kHz spacing could contain around 6000 useful REs (i.e. typically providing at least 6000 information bits, even including coding and other overheads and without considering any spatial multiplexing.). The size of one control channel message for resources assignment is likely to be in the range 50-100 bits. With a small number of users per cell, there will not be many control channel messages in one OFDM symbol, so the remaining bits should be used for data.

Nokia	We suggest defining a subframe as an abstract reference construct that is of 1 ms duration and can be considered as two 7-symbol 15 kHz SCS slots. This fixed definition would be used as an anchor to which the other definitions and scaled numerologies refer to. I.e. sub-frame would be the same, no matter what SCS is used in the cell, or on what frequency band the cell operates.
Sony	The slot may begin with an uplink transmission. This can be used in Massive MIMO where the uplink transmission at the beginning provides RS for the base station to determine the precoding in the downlink. The uplink RS in the beginning can be followed by a gap and then downlink transmissions.  The diagram illustrates three subframe configurations (A, B, C) within a coherence time and coherence bandwidth. Configuration A shows URS-1 and URS-2 in the UL portion, followed by a gap and then DL. Configuration B shows URS-1 and URS-2 in the UL portion, followed by a gap and then UL. Configuration C shows URS-1 and URS-2 in the UL portion, followed by a gap and then DL. Arrows indicate the flow of data and the processing delay at the TRP.
CATT	We consider subframe is used as a reference counter from network perspective. The DL/GP/UL configuration of slot should be UE-specific.

3 Conclusions

Proposal 1: For the slot duration y , at least the following should be supported

- Configurations supporting slot $y = 7$ and 14 symbols

Proposal 2: For transmission durations of EMBB, at least the following should be supported

- Ability to define transmission duration through the aggregation of slots
 - Configuration may be through semi-static RRC signaling or dynamic L1 indication
 - FFS: if any aspects of aggregation or related control should be captured in specification
- Ability to configure the minimum transmission duration of more than 14 symbols at higher SCS
 - FFS: how to define the minimum
 - Option 1. Minimum value of SCS (e.g., 120kHz needs 28 symbols)
 - Option 2. Minimum transmission duration of [0.125ms]
 - Option 1: Configuration of y to be larger than 14
 - Option 2: Aggregation of slots to achieve

Proposal 3: *The NR frame structure should support both slots and mini-slots.*

- *FFS: Timeline granularity for monitoring control of the mini-slot*

Proposal 4: *The NR frame structure should at least support the following*

- *Periodicities for downlink and uplink control equal to 250us, 500us, and 1m*
- *Longer intervals or aperiodicity resulting from e.g., semistatic or dynamic slot aggregation*

Proposal 5: *Define a subframe duration as 1 ms with a reference numerology 14-symbols at 15 kHz SCS.*