**3GPP TSG RAN WG1 #110 R1-2207752**

**Toulouse, France, August 22nd – 26th, 2022**

**Agenda item:** 9.10.2

**Source:** Moderator (NTT DOCOMO, INC.)

**Title:** Summary of discussion on multi-carrier UL Tx switching scheme

**Document for:** Discussion and Decision

1. Introduction

This contribution summarizes contributions submitted to AI 8.16.5 regarding the multi-carrier UL Tx switching scheme.

1. References

[1] R1-2205863 Discussion on multi-carrier UL Tx switching Huawei, HiSilicon

[2] R1-2205963 Discussion on Multi-carrier UL Tx switching scheme ZTE

[3] R1-2206006 Discussion on multi-carrier UL Tx switching scheme Spreadtrum Communications

[4] R1-2206060 Discussion on UL TX switching vivo

[5] R1-2206130 Considerations on Multi-carrier UL Tx switching scheme Sony

[6] R1-2206177 Views on multi-carrier UL Tx switching scheme Fujitsu

[7] R1-2206327 Discussion on multi-carrier UL Tx switching scheme OPPO

[8] R1-2206383 Discussion on multi-carrier UL Tx switching scheme CATT

[9] R1-2206434 On Multi-Carrier UL Tx Switching Nokia, Nokia Shanghai Bell

[10] R1-2206600 Discussions on multi-carrier UL Tx switching scheme Intel Corporation

[11] R1-2206628 Discussion on multi-carrier UL Tx switching scheme Xiaomi

[12] R1-2206664 Multi-carrier UL Tx switching scheme InterDigital, Inc.

[13] R1-2206701 Discussion on UL Tx switching across up to 3 or 4 bands China Telecom

[14] R1-2206845 On multi-carrier UL Tx switching Samsung

[15] R1-2206930 Discussion on multi-carrier UL Tx switching scheme CMCC

[16] R1-2206986 On multi-carrier UL Tx switching scheme MediaTek Inc.

[17] R1-2207041 Discussion on Multi-carrier UL Tx switching scheme LG Electronics

[18] R1-2207252 Discussion on Rel-18 UL Tx switching Qualcomm Incorporated

[19] R1-2207350 On multi-carrier UL Tx switching Apple

[20] R1-2207425 Discussion on multi-carrier UL Tx switching scheme NTT DOCOMO, INC.

[21] R1-2207442 Multi-carrier UL Tx switching Ericsson

[22] R1-2207555 Discussion on multi-carrier UL Tx switching scheme Google Inc.

[23] RP-221435 Revised WID on Multi-carrier enhancements NTT DOCOMO, INC.

[24] RP-221880 Discussion on target scenarios for Rel-18 UL Tx switching in NR Multi-carrier enhancements WI NTT DOCOMO, INC.

[25] RAN1 Chair’s Notes RAN1#109-e meeting

1. Discussions on the possible mechanisms for dynamic Tx carrier switching across the configured bands

According to the following agreement made at the last RAN1 meeting, companies provided their investigation results in contributions. In this section, companies’ observations on each alternative are summarized, and then companies’ proposals for the down-selection are also summarized.

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| **Agreement**Companies are encouraged to investigate pros and cons of following possible mechanisms for dynamic Tx carrier switching across the configured bands, and RAN1 strives for the down-selection at RAN1#110* Alt.1: Dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission
* Alt.2: NW indicates 2 bands out of the configured bands (3 or 4 bands) via DCI or MAC-CE, and dynamic Tx carrier switching between indicated bands is same as Rel-17
* Alt.3: One anchor band is selected among configured bands (3 or 4 bands), and dynamic Tx carrier switching can be performed only from the anchor band to a non-anchor band and from a non-anchor band to the anchor band
* Note: Other mechanisms are not precluded
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## 3.1 Views on Alt.1: Dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission

In contributions, following observations were made regarding Alt.1.

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| [1] HW, HiSi | In Rel-18, the Alt 1 can be directly applied to dynamic UL Tx switching among 3 bands or 4 bands, if units of memory to store essential baseband and RF information for UL transmissions are increased accordingly. For example, for the 3 bands scenario in Figure 4, three units of memory are occupied by 3 bands and each unit of memory is exclusive to one band for UL transmission. Therefore, compared with fast UL Tx switching across 2 bands with 2 units of memory in Rel-17, the UE memory of Alt 1 UE in Rel-18 is increased, while Alt 1 could have the best performance with full scheduling flexibility.***Observation 1:*** *Similar to Rel-17, fast UL Tx switching via DCI scheduling can be enabled in Rel-18 if a UE has adequate* *memory to store information for each band.****Observation 2:*** *From UE complexity perspective, as number of bands increases, the required size of memory increases.****Observation 3:*** *The same mechanism of memory sharing is applicable to both UL-CA Option 1 and 2. But with the same limited UE memory size, there is more scheduling restriction to minimize transmission interruption for UL-CA Option 2 than Option 1 simply because more UE memory are occupied at one time for Option 2 than Option 1.*It can be found that Alt 1 obtains up to 44.8% uplink average UPT gain compared with Baseline although Alt 1 has longer UE preparation procedure time and longer time interval of two successive switching. Moreover, Alt 1 also can obtain up to 28.9% uplink average UPT gain compared with Baseline when considering longer switching period.***Observation 5:*** *Even with additional scheduling restriction required by UE memory reduction, i.e. longer UE preparation time and time interval of two successive UL Tx switching, Alt 1 can bring average UPT gain up to ~45% compared with Baseline with different switching periods.****Observation 7:*** *Alt 1 is always the best in term of performance irrespective of UE memory sharing. Alt 1 with UE memory sharing is the best in term of both UE complexity and performance.* |
| [2] ZTE | * Alt.1 allows UE to switch from any band to any other band. New tables for different cases for 3 or 4 bands need to be firstly defined respectively, and then RAN1 needs to identify each switching case and potential ambiguity issues respectively.

Following the design principle of Rel-17, many scenarios should be considered under different combinations of supported (number of Tx per band, number of carriers per band). Figure 1 illustrates the possible scenarios when taking different combinations into account. We propose that we should first identify which scenarios are to be supported in Rel-18 with higher priority.For different scenarios, the mapping of Tx chains and antenna ports may be different. We may need to define the mapping case by case. Take CA with Option 2 under 3 bands with 2Tx-2Tx-2Tx chain configuration with one carrier per band as an example, the mapping of Tx chains and antenna ports may be defined as Table 2.Although the mapping of Tx chains and antenna ports should be defined case by case, the UE behavior defined in Rel-16/17 can be reused for most of the switching cases, except the switching among Case 1-x (x=1,2,3). For example, as listed in Table 2, when the UE is to transmit a 1-port transmission on Carrier 3 on band C, and if the preceding transmission was a 1-port transmission on Carrier 1 and/or a 1-port transmission on Carrier 2 and the UE was under the operation state of Case 1-1, then a switching gap is required. Another issue is the potential ambiguity issue. Compared to Rel-17, the ambiguity issue in Rel-18 is more complex. As highlighted in Table 2, if UL Tx switching is triggered for 1-port transmission on Carrier 1 on Band A, (i.e. 1P+0P+0P in Table 2), the state of Tx chain to support such transmission can be in Case 1-1, Case 1-3 or Case 2-1. And the preceding transmission for such switching also includes several cases. Figure 2 shows the possible transitions for different preceding transmission. The situation may be more complex for 4 bands.***Observation 3****: Based on potential Alt.1, network can indicate any UL carrier within up to 2 bands for UL transmission. The following issues should be discussed for 3 bands and 4 bands respectively.** *Identify the supported scenarios, including the number of Tx antennas for each band, number of continuous UL carriers and number of bands.*
* *Define the mapping of Tx chains and antenna ports for the identified scenarios case by case.*
* *Introduce new switching case(s) for Rel-18 for up to 3 or 4 bands.*
* *Resolve the potential ambiguity issues.*

Overall, from our perspective, if Alt.1 is adopted, all the following 32 combinations need to be considered as shown in Figure 4. The 12 combinations for 3-band case are listed as below: {A3-1, B3-1}, {A3-2, B3-1}, {A3-3, B3-1}, {A3-4, B3-1}, {A3-1, B3-2}, {A3-2, B3-2}, {A3-3, B3-2}, {A3-4, B3-2}, {A3-1, B3-3}, {A3-2, B3-3}, {A3-3, B3-3}, {A3-4, B3-3}. The 20 combinations for 4-band case are listed as below: {A4-1, B4-1}, {A4-2, B4-1}, {A4-3, B4-1}, {A4-4, B4-1}, {A4-5, B4-1},{A4-1, B4-2}, {A4-2, B4-2}, {A4-3, B4-2}, {A4-4, B4-2}, {A4-5, B4-2}, {A4-1, B4-3}, {A4-2, B4-3}, {A4-3, B4-3}, {A4-4, B4-3}, {A4-5, B4-3},{A4-1, B4-4}, {A4-2, B4-4}, {A4-3, B4-4}, {A4-4, B4-4}, {A4-5, B4-4}.Take combination {A4-1, B4-1} as an example, it means UE supports UL Tx switching across 4 bands and each of the 4 bands has only one carrier and all the 4 bands support up to 2Tx.***Observation 4****: If Alt.1 is adopted, all the 32 different combinations should be considered for Rel-18 UL Tx switching across 3/4 bands.** *The 12 combinations for 3-band case: {A3-1, B3-1}, {A3-2, B3-1}, {A3-3, B3-1}, {A3-4, B3-1}, {A3-1, B3-2}, {A3-2, B3-2}, {A3-3, B3-2}, {A3-4, B3-2}, {A3-1, B3-3}, {A3-2, B3-3}, {A3-3, B3-3}, {A3-4, B3-3}.*
* *The 20 combinations for 4-band case: {A4-1, B4-1}, {A4-2, B4-1}, {A4-3, B4-1}, {A4-4, B4-1}, {A4-5, B4-1},{A4-1, B4-2}, {A4-2, B4-2}, {A4-3, B4-2}, {A4-4, B4-2}, {A4-5, B4-2}, {A4-1, B4-3}, {A4-2, B4-3}, {A4-3, B4-3}, {A4-4, B4-3}, {A4-5, B4-3},{A4-1, B4-4}, {A4-2, B4-4}, {A4-3, B4-4}, {A4-4, B4-4}, {A4-5, B4-4}.*
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| [3] SPRD | According to the mechanisms for dynamic Tx carrier switching, three alternatives were agreed. Among the Alt1/2/3, we support Alt 1 with some complexity reductions e.g. reported by UE capabilities. * First, it can totally reuse the UL Tx switching mechanisms from Rel-17, based on the UL scheduling, via UL grant and RRC configuration for UL transmission. Considering the short TU allocated to this WI, we hope it can reuse the current mechanism as much as possible to decrease the specification impact.
* Second, the UL Tx switching mechanism from Rel-17 can provide the largest scheduling flexibility. Alt2 suggested NW indicates 2 bands out of the configured bands (3 or 4 bands) via DCI or MAC-CE, and dynamic Tx carrier switching between indicated bands is same as Rel-17. However, if the NW indicates 2 bands by DCI, this DCI is a new type of DCI, may be based on non-scheduled DCI formats. If the MAC-CE is applied, new MAC-CE requires large efforts, which may not realistic due to limit TU. Furthermore, this new switching DCI/MAC-CE still have to face the same problems that which set of bands can be switched form/into, including the numerous switching cases etc.
* Third, if additional UE capabilities are allowed to report, Alt 1 with complexity reduction methods can largely reduce the UE implementation complexity. Large portion of switching cases can be down scaled. The next section gives more discussion towards the benefit of these complexity reduction methods.
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| [4] vivo | Alt.1 reuses the Rel-16/Rel-17 trigger mechanism, which is based on the DCI or higher layer configuration. Moreover, Tx can be switched among all the supported cases discussed in section 2.3, thus allowing the highest flexibility. Even though the ambiguity issue becomes a bit worse owing to the increased number of switching cases with larger bands number, it can be eliminated by RRC indication similar to Rel-17. Consequently, more bits are needed to indicate the Tx chain states with the same port mapping. For example, 2 bits are used to distinguish the Tx chain state{1T+1T+0T+0T}, {1T+0T+1T+0T}, {1T+0T+0T+1T}, {2T+0T+0T+0T} when antenna port mapping is {1P+0P+0P+0P}. Additionally, as analyzed in section 2.3, as some switching cases involving only two bands when three or four bands are configured are exactly the same as 2T-2T and 1T-2T switching modes in R16/17, reusing the R16/R17 Tx switching framework ensures backward compatibility at least for these cases. |
| [5] Sony | Alt.1 is the only alternative that potentially can harvest the full potential of having 3 or 4 bands available. Concerns may be signalling to configure the UE dynamically, which, may require some additional overhead and possible limitations caused by long switch duration indicated in [2].To harvest the potential of the available channels we believe that Alt 1 is the most relevant. **Observation 1: To harvest the potential of the available channels we believe that Alt 1 is the most relevant.** |
| [6] FJT | The benefit of Alt-1 is the flexibility, and the maximum performance gain can be achieved by this flexibility while the highest complexity is required to UEs. Meanwhile, Alt-2 can achieve the least functional change on top Rel-17 Tx switching. Alt-3 would be helpful from UE implementation perspective because UE is not required to manage many switching combinations. In our understanding, the gain by this technology is derived by the efficient use of Tx chain (i.e. unused Tx chain in a carrier with DL slot is switched to a carrier with UL slot) as described in section 2.1. Therefore, the switching pattern is something predetermined, and we don’t think the scheduling restriction introduced by Alt-2 or Alt-3 brings severe performance degradation.  |
| [7] OPPO | ***Proposal 1: Alt 1, i.e. Dynamic Tx carrier switching across all the supported switching cases, is preferred due to less spec effort and low switch latency.*** |
| [8] CATT | * Advantage: Any carrier can be scheduled to transmit uplink signal/data, and the benefit of diversity of UL Tx switching pairs can be obtained.
* Disadvantage: Two potential issues require to be further studied.
	+ Identify new switching cases for 3 or 4 band switching.
	+ Ambiguity issue on switching case.

For the first potential issue, new UL TX switching cases for 3/4 bands are discussed in section 2.2. Two new UL TX switching cases are identified for 3 bands operation and three new UL TX switching cases are identified for 4 bands operation. For the second potential issue, the ambiguity issue of UL Tx switching among 3/4 bands is similar to UL Tx switching between 2 bands in Rel-17. Hence, the method specified in Rel-17 for ambiguity issue can be as baseline to solve ambiguity issue of Rel-18, for example, applying RRC signalling to indicate next UL TX switching case.  |
| [9] NOK, NSB | From logical functionality perspective this is an attractive alternative as it allows the gNB to dynamically schedule any UL transmission as long as the UE capability constraints on how the two transmit chains can operate are respected. If e.g. the UE is able to transmit 2Tx on all bands and it is also able to transmit 1Tx on each band on any two band pairs, then the gNB scheduler can freely pick any UL to transmit 2Tx or any UL pair to each transmit 1Tx without any further preparation or pre-configuration.From specification compatibility perspective this alternative should work directly with the definitions in TS38.214 subclause 6.1.6.2 ”*Uplink switching for carrier aggregation*”. However, there are new switching cases that may require additional specification.From UE capability perspective, it would be important to agree that UE supporting a set different pairs of Tx to band mapping cases, then the UE should also be able to switch from any one mapping to any other mapping of the Tx chains to bands directly and with the same switching transient.**Observation 1:** Alt1 offers the best flexibility, but the specification and UE capability implications are not fully clear |
| [11] Xiaomi | ***Observation 1: UL Tx switching across up to 3 or 4 bands with restriction of up to 2 Tx simultaneous transmission for FR1 UEs is beneficial to the flexibility and robustness of uplink transmission.***With regard to the maximum number of UL bands for UL Tx switching, 4 UL bands can provide more flexibility to scheduling while the standard impacts are similar with 3 UL bands. Hence we prefer to support up to 4 UL bands.***Proposal 1: If UL Tx switching across more than 2 bands is supported, the band list contains up to 4 bands with restriction of up to 2 Tx simultaneous transmission for FR1 UEs.***Alt.1 can exploit all the benefits we can expect from UL Tx switching across more than 2 UL bands.The major concern on Alt.1 is that it may increase the UE complexity. However, no matter which alternative is adopted in the end, UE has to support UL Tx switching across more than two bands eventually. In the other words, UE has the capability to support UL Tx switching if more than two bands is supported. Furthermore, the UL Tx switching always happens between two bands. From this perspective, we don’t see additional UE complexity will be brought by alt.1. |
| [13] CT | Alt.1 provides full flexibility for UL scheduling to utilize the available UL carriers. Similar as Rel-16/Rel-17 specification procedure, the mapping between Tx chains and UL transmission antenna ports needs to be listed for total 3 or 4 bands cases. Then the Tx switching cases are to be identified based on it as wells as the switching cases having ambiguity issues. It can be considered whether Rel-17 RRC configuration principle could be reused to address the ambiguity issues. The switching cases can be classified and some of them are already covered by the current specification. The specification impact is to capture several new Tx switching cases. The detailed switching mechanism for the targeted scenarios is discussed in the following sections. Under Alt.1 framework, there are ways to be discussed to address the concern on UE/gNB complexity increase. |
| [15] CMCC | The most advantage of Alt 1 is to reuse Rel-15/16 principle but more standard efforts are needed to define the mapping between UL transmission ports and Tx chains, which is not a forward compatible solution if more UL Tx switching scenarios are introduced. |
| [17]LG | In case of Alt 1, UL Tx switching can be performed in all the supported switching cases over 3 or 4 UL bands. It means that there is no restriction in preforming of UL transmission scheduled by DCI or configured by RRC. Since Alt 1 is a method that allows all switching cases in the configured UL bands, large amount gain is expected due to the increased number of UL bands in Rel-18 Tx switching compared to Rel-16/17. In addition, there is no need to discuss about a method of indicating UL band for Tx switching.  |
| [18] QC | Among the three alternatives, Alt. 1 is dynamic switching between any 2 bands among the configured 3 or 4 bands, which would be 6 switching cases for 3 bands switching and 10 switching cases for 4 bands switching.For Alt. 1 & Alt. 2, current RRC configuration may not work as there are some chance that none of the two dynamic switch bands is configured with switching period location. Take three bands switching as an example, if the RRC configuration indicates band A to take the switching period. Alt. 1 allows dynamic switching between any two bands. If the switching is between band B and C, there would be ambiguity as none of them is configured with switching period location.**Observation: For down-selection among three alternatives, minimize the standard efforts should be preferred. One example is which band to take the switching period,** * **Alt. 1 and Alt. 2 would require new configuration mechanism as current RRC configured switching period location may not work if none of the two dynamic switch bands is configured with switching period location.**
* **Alt. 3 could reuse current configuration mechanism with minimized efforts as the switching period could be configured on the anchor band or non-anchor band.**
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| [19] Apple |

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| **Alternatives** | **Pros** | **Cons** |
| **Alt 1**: Dynamic Tx carrier switching across all supported cases for 3 or 4 bands | * Full flexibility
* All configured bands available for switching at any scheduling instance
 | * Frequent Retuning of UL Tx chains needed whenever one or two band changes due to switching
* Large number of switching cases need to be specified for 3 or 4 bands
* Specifying potentially different switching gaps corresponding to different switching categories such as only 1 band change, both bands change, etc.
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| [20] DCM | * + Since Alt.1 allows dynamic switching across all the supported switching cases, the number of candidate bands for dynamic switching at each Tx chain is increased from Rel-17 as below. It may mean that the complexity of UL Tx switching is increased if the complexity is based on number of candidate bands for dynamic switching at each Tx chain.
		- [Reference] In Rel-17, the number of candidate bands for dynamic switching at each Tx chain is 2, i.e., band A and B.
		- In Alt.1, the number of candidate bands for dynamic switching at each Tx chain is 3 or 4, i.e., band A, B and C (and D).
	+ On the other hand, the performance gain of Alt.1 has been shown based on simurestion results at the RAN1#109-e meeting. Since there is no restriction on target switching band/case in Alt.1, Alt.1 should have better performance than Alt.2/3 in terms of both single user throughput and system performance such as flexible offloading across bands.

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| Alt.1 | * Higher scheduling flexibility and higher performance compared with Alt.2/3
 | * The larger number of candidate bands for dynamic switching at each Tx chain compared with Alt.2/3 in some sense
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**Observation 1: The complexity of the switching mechanism may depend on the number of candidate bands for dynamic switching at each Tx chain and/or the number of switching patterns for dynamic switching at each Tx chain.*** **All the switching cases would be supported in Alt.1/2/3, but Alt.2 requires an additional procedure (i.e., reconfiguration of 2 candidate bands for dynamic switching based on DCI or MAC-CE indication) for direct switching between specific cases, and Alt.3 has a restriction for direct switching between specific cases.**

**Observation 2: There may be no significant difference among Alt.1, 2 and 3 in terms of the number of the candidare bands for dynamic switching at each Tx chain.*** **Alt.2 allows a relaxed timeline for “dynamic switching” by requiring DCI or MAC-CE indication compared with Alt.1/3, but the number of the candidate bands for (semi-)dynamic switching at each Tx chain is same as Alt.1.**
* **Alt.3 has smaller number of candidate bands for dynamic switching at Tx chain when the Tx chain is currently associated with non-anchor band, but Alt.3 has the same number of candidate bands for dynamic switching at Tx chain when the Tx chain is currently associated with anchor band as in Alt.1.**

**Observation 3: Alt.2 and Alt.3 have scheduling restriction (delay) for some band(s) and hence the performance should be lower than that of Alt.1.** |
| [21] E/// | Alt 1 is the super set which provides full flexibility in operation and is preferred from NW operation point of view. Alt 2 and Alt 3 are proposed claiming to simplify the operation or reduce UE complexity, respectively. We discuss our understanding of Alt 2 and Alt 3 first, and the challenges and issues that we observe with these alternatives. We further explain that how Alt 1 can be updated to address the underlying concerns that in our understanding, motivated proposing alternatives 2 and 3.It is observed that in Alt 1, transition between any two states does not rely on an intermediate state or additional dynamic signalling as opposed to Alt 2 and Alt 3. This property is of high importance for finding dynamic UL Tx switching across 3 bands beneficial to use. The operation based on Alt 2 and Alt 3 imposes dependency between scheduled UL transmissions on 3 bands. Therefore, it complicates scheduling since feasibility of any scheduled transmission relies on the previous UL transmissions or transition enabler DCI/MAC-CE. The dependency is not only determinantal for the NW operation, but also for the system throughput due to error propagation in case of intermediate miss detection at UEs. If an UL grant is missed, not only a UE misses the corresponding UL transmission, but also invalidates the followed up scheduled UL transmissions. Moreover, regarding Alt 2, in addition to the negative consequences of dependent scheduling, one can clearly observe that it requires additional DCI/MAC-CE overhead for enabling state transitions.Therefore, in our view if UL Tx switching is to be supported, only operation based on Alt1 is meaningful. Any approach based on Alt 2 and Alt 3 clearly makes the promised benefits and usefulness of dynamic UL Tx switching across more than 2 bands questionable. The concerns raised towards UE complexity should properly addressed with Alt 1 framework to have a meaningful design. In our view, to support Alt 1 while addressing the claimed UE complexity, the notion of anchor band to switch a TX chain to/from, can be reflected properly in the procedure such that the relaxed UE complexity does not result in scheduling complexity. 1. UL Tx switching across 3 or 4 bands design based on Alt 2 and Alt 3 results in scheduling dependency and error propagation. Any design based on Alt 2 and Alt 3 makes the promised benefits and usefulness of dynamic UL Tx switching across more than 2 bands questionable.
2. If UL Tx switching across 3 or 4 bands is supported, only operation based on Alt1 that properly addresses UE complexity is meaningful.
3. To support Alt 1 while addressing the claimed UE complexity, the notion of anchor band to switch a TX chain to/from, can be reflected properly in the procedure such that the relaxed UE complexity does not result in scheduling complexity.
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| [22] Google | Alt-1 is similar to the UL Tx switching in Rel. 17, which all antenna states are supported, except that the number of bands increases from 2 to 3 or/and 4. As we increase the number of bands, the number of antenna states and the complexity increase accordingly. As depicted in Table 1 and Table 2, there will be 6 and 10 antenna state cases in 3 and 4 bands scenarios. However, not all the cases are applicable in practical, which still depends on UE implementation. For example, a UE may not be able to support 2T in all carriers, e.g., carrier 2, then case 1 (0T+2T+0T) in Table 1 is not applicable. In another example, a UE may not support simultaneous transmissions in carrier 1 and carrier 2, thereby case 4 (1T+1T+0T) in Table 1 is not applicable. **Observation 1: Increasing the number of bands for UL Tx switching will increase the number of antenna states, but the number of supported antenna state cases and the complexity are determined according to UE implementation.**  |

Based on above, the situation can be summarized as below.

### Summary 3.1

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| * Alt.1: Dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission
	+ Best performance thanks to full flexibility for scheduling and UL Tx switching [1, 3, 4, 5, 6, 8, 9, 11, 13, 17, 19, 20, 21]
	+ Reuse of Rel-16/17 switching mechanisms based on UL scheduling, i.e., less spec effort [3, 4, 7, 9, 13, 17]
	+ There are new switching patterns where more than 2 bands are involved in a switching [2, 8, 9, 19]
	+ Regarding ambiguous state issue, the number of potential Tx chain states increases [2, 4, 8, 13]
	+ Complexity can be reduced e.g., by introducing additional UE capabilities [3, 13, 21, 22]
	+ Largest number of switching cases [2, 19, 22]
		- Complexity is not so different from other alternatives [1, 11, 20]
	+ Not a forward compatible if more UL Tx switching scenarios are introduced [15]
	+ Current RRC configuration on switching period location may not work [18]
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The moderator would like to ask companies to provide feedback if any on the above summary.

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| Company | Comment |
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## 3.2 Views on Alt.2: NW indicates 2 bands out of the configured bands (3 or 4 bands) via DCI or MAC-CE, and dynamic Tx carrier switching between indicated bands is same as Rel-17

In contributions, following observations were made regarding Alt.2.

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| [1] HW, HiSi | The mechanisms of Alt 2 are two stage switching where the 1st stage switching is between band groups of two bands, and the 2nd stage switching is within the band group of two bands which is same as UL Tx switching between 2 bands in Rel-17. Obviously, Alt 2 has following drawbacks,* **Extra long UL interruption**: The 1st stage switching is between band groups of two bands and causes much longer switching interruption than 2nd stage switching.
* **Higher package loss rate**: Extra interruption to HARQ retransmission on the switch-from band group by the 1st stage switching, resulting in higher package loss rate.
* **Less scheduling flexibility:** Due to two stage switching, Alt 2 has less scheduling flexibility.

As shown in Figure 8, the switching interruption of 1st stage switching is much longer than 2nd stage switching because all UE memory are flushed and reloaded at the same time required by the 1st stage switching for the new group of bands and there is only RF switching during 2nd stage switching interruption. Moreover, the HARQ retransmission on band B or band A is prevented after the 1st stage switching in Alt 2. Therefore, there is extra interruption to HARQ retransmission on the switch-from band group by the 1st stage switching, which results in high package loss rate in Alt 2.***Observation 4:*** *Alt 2 has worse performance than Alt 1 due to longer UL interruption and more scheduling restrictions.* |
| [2] ZTE | * Alt.2 is designed with the intention of reusing Rel-16/17 UL Tx switching as much as possible. Two sub alternatives of Alt.2 can be considered, i.e., Alt.2 with DCI indicating band pair and Alt.2 with MAC-CE indicating band pair. For Alt.2 with MAC-CE indicating band pair, gNB first indicates 2 bands for subsequent UL transmission, and then Rel-16/17 UL Tx switching can be performed within the 2 bands until next gNB indication. For Alt. 2 with DCI indicating band pair, it is similar as Alt.1, where the UL scheduling DCI can be used to indicate the band pair and schedule UL transmission at the same time. One new field may be needed in the UL scheduling DCI format.

In order to clarify different alternatives more accurately, Alt.2 can be further divided as two sub alternatives, i.e., Alt.2 with DCI indicating band pair and Alt.2 with MAC-CE indicating band pair.* **Alt.2 with DCI indicating band pair (1-stage indication):** One new filed is introduced in the UL scheduling DCI format (e.g., DCI format 0\_1/0\_2) to indicate the band pair for subsequent UL transmission. The UL scheduling DCI format can be used to schedule UL transmission and indicate band pair at the same time. Thus, Alt.2 with DCI indicating band pair is a 1-stage indication. This alternative can achieve the same Tx switching flexibility as Alt.1 and won’t introduce any additional delay compared with Alt.1. UE performs UL Tx switching between the two indicated bands until new indication arrives.
* **Alt.2 with MAC-CE indicating band pair (2-stage indication):** One MAC-CE is introduced to indicate the band pair for subsequent UL transmission. UE performs UL Tx switching between the two bands indicated by the band pair until new indication arrives. Thus, Alt.2 with MAC-CE indicating band pair is a 2-stage indication. At least from RAN1 perspective, 3ms processing time is reserved for MAC-CE processing. After this MAC-CE processing time, a switching period is required for UE to perform UL Tx switching. Similar as the existing specification, UE can still transmit and receive during the MAC-CE processing time. Thus, the switching period for UL Tx switching is the legacy UL Tx switching period. One potential issue is whether we need to define new switching period for band pair switching. Based on our understanding, essentially, the so-called “band pair switching” is the same as “Tx switching” since it is the same as that UE switches its Tx from one band to another band. Thus, the legacy UL Tx switching period can be reused for band pair switching

Base on the Alt.2, UE will perform UL Tx switching within the 2 indicated bands until the next indication received. The legacy Rel-16/17 UL Tx switching can be reused, including at least the following.* Legacy tables can be reused within the 2 indicated bands
* The legacy switching cases can be reused
* The legacy solution for ambiguity issues can be reused

Based on the above analysis, we provide the following observation.***Observation 5****: Alt.2 can be divided into two sub alternatives.** + ***Alt.2 with DCI indicating band pair (1-stage indication):*** *One new filed is introduced in the UL scheduling DCI format (e.g., DCI format 0\_1/0-2) to indicate the band pair for subsequent UL transmission. This alternative can achieve the same Tx switching flexibility as Alt.1 and won’t introduce any additional delay compared with Alt.1.*
	+ ***Alt.2 with MAC-CE indicating band pair (2-stage indication):*** *One MAC-CE is introduced to indicate the band pair for subsequent UL transmission. UE performs UL Tx switching between the band pair indicated by the band pair. At least from RAN1 perspective, 3ms processing time is reserved for MAC-CE processing. After this MAC-CE processing time, a switching period is required for UE to perform UL Tx switching. Similar as the existing specification, UE can still transmit and receive during the MAC-CE processing time.*
	+ *Note: The legacy UL Tx switching period can be reused for band pair switching.*

***Observation 6****: Necessities of indicating band pair.** + - 1. *After indicating the band pair, all the Rel-16/17 UL Tx switching specification/mechanism can be reused for the two indicated bands.*
			2. *The RAN4 requirements and RAN2 signalling framework are based on the band pair. Without indicating band pair, RAN4 and RAN2 has to define new framework for requirements and signalling.*
			3. *Without indicating band pair, network/UE has to assume the maximum switching period (& DL interruption) among all the potential UL Tx switching case for each UL Tx switching. Based on company’s simulation results [3], longer switching period will result in smaller gain of UL Tx switching. Since Alt.2 can indicate band pair, the switching period for each band pair can be reported and applied.*
			4. *For UE indicating band combination A+B+C, if UE is going to transmit 1 port UL transmission on band C if the preceding transmission with 1P+1P on band (A+B), UE is not clear whether UE should switch its Tx to band (A+C) or band (B+C). Meanwhile, UE is not clear which switching period should be applied. If band pair is indicated, then the issue can be addressed.*
			5. *Without indicating clear band pair for the UE, Alt.1 requires unnecessary switching periods even for SUL/CA Option1.*
			6. *If UE supports HW resources (e.g., cache or RF configuration) sharing between different bands, UE can switch the HW resources from one band pair to another band pair together with the UL Tx switching. Thus, the cost for UE implementation can be saved.*

Table 8. Mean UPT for Mechanism#1 for 4-band case

|  |  |  |
| --- | --- | --- |
|  | Mean UPT (Mbps) | Gain |
| Baseline(Rel-16/17 UL Tx switching) | 99.9406 |  |
| Rel-18 UL Tx switching**Alt. 1** | 123.8781 | 23.95% |
| Rel-18 UL Tx switching**Alt. 2 with 10 slots processing time** | 123.8581 | 23.93% |
| Rel-18 UL Tx switching**Alt. 2 with 20 slots processing time** | 123.5321 | 23.61% |

Table 9. Mean UPT for Mechanism#2 for 4-band case

|  |  |  |
| --- | --- | --- |
|  | Mean UPT (Mbps) | Gain |
| Baseline(Rel-16/17 UL Tx switching) | 113.0085 |  |
| Rel-18 UL Tx switching**Alt. 1** | 123.8781 | 9.62% |
| Rel-18 UL Tx switching**Alt. 2 with 10 slots processing time** | 123.8581 | 9.6% |
| Rel-18 UL Tx switching**Alt. 2 with 20 slots processing time** | 123.5321 | 9.31% |

The reason why Alt.2 with 5ms/10ms processing time can reach almost the same performance as Alt.1 is because UE can always select at least one band within the current band pair for UL transmission. There is low probability that both of the bands within the current band pair are not suitable for UL transmission. Basically, there are two reasons triggering band pair switching, i.e., (1) road balance (2) channel condition change of each band. We counted the number of band pair switching and the number of UL Tx switching within the band pair. Based on our simulation, * for Alt.2 with 5ms processing time, among all the switching (number of band pair switching + number of UL Tx switching within the band pair), the number of band pair switching occupies only 0.43%;
* for Alt.2 with 10ms processing time, among all the switching (number of band pair switching + number of UL Tx switching within the band pair), the number of band pair switching occupies only 0.55%;

In other words, UE switches its band pair after around 200 times of UL Tx switching within the current band pair on average. It is obvious that the band pair switching doesn’t happen frequently.***Observation 7****: UE doesn’t change its band pair frequently. In our simulation, among all the switching (number of band pair switching + number of UL Tx switching within the band pair), the number of band pair switching occupies around 0.43% - 0.55%. In other words, UE switches its band pair after around 200 times of UL Tx switching within the current band pair on average.****Observation 8****: Alt. 2 with 5ms/10ms MAC-CE processing time reaches the same performance as Alt.1.*  |
| [4] vivo | For Alt.2, two bands out of the configured bands are indicated by DCI or MAC CE. After receiving the band indication successfully, TX switching is expected to be within the two indicated bands, thus the Rel-16/Rel-17 dynamic Tx switching mechanism can be reused. However, there are several issues to be addressed. Firstly, the supported Tx switching between the preceding two bands and the indicated later two bands should be defined. Secondly, the initial Tx state for the indicated two bands should be decided. If the initial Tx state is configured by higher layer, additional signaling overhead and latency would be introduced for the objective when the target Tx state is different from the initial Tx state. For example, assuming that the indicated two bands are band C and band D, and the UE is scheduled to transmit a 2-port transmission on band C while the initial Tx state is semi-statically configured as “1T+1T”, then UE has to switch to the initial TX state first, then switch to the target Tx state “2T+0T”, requires additional signaling to trigger the switching from “1T+1T” to “2T+0T” and results in additional latency. Alternatively, if the initial Tx state is dynamically indicated by a new DCI format, Alt.2 has similar scheduling flexibility as well as similar complexity as alt1. Third, if the band indication is carried by MAC CE, at least the timeline (e.g., HARQ processing time/PDSCH processing time for MAC CE) and additional RAN2 impact should be considered for the Tx switching. Moreover, Tx switching can only perform after the ACK is generated for the MAC CE. Thus, the UE behaviors for the case of the DTX or decoding failure of the band indication signaling should be specified. |
| [6] FJT | The benefit of Alt-1 is the flexibility, and the maximum performance gain can be achieved by this flexibility while the highest complexity is required to UEs. Meanwhile, Alt-2 can achieve the least functional change on top Rel-17 Tx switching. Alt-3 would be helpful from UE implementation perspective because UE is not required to manage many switching combinations. In our understanding, the gain by this technology is derived by the efficient use of Tx chain (i.e. unused Tx chain in a carrier with DL slot is switched to a carrier with UL slot) as described in section 2.1. Therefore, the switching pattern is something predetermined, and we don’t think the scheduling restriction introduced by Alt-2 or Alt-3 brings severe performance degradation.  |
| [7] OPPO | For Alt2, the procedure to switch from one 2-band combination to another 2-band combination should be studied, e.g. whether there is a restriction on band combination for switch, the initial state for 2 band combination and so on. And it increases switch latency due to switch procedure includes band combination switch and band switch within one band combination and each step requires one switch period. |
| [8] CATT | * Advantage: Within the indicated switching band pair, UL Tx switching scheme of Rel-16/Rel-17 can be re-used, and the ambiguity issue can be avoided.
* Disadvantage: The issues on the switching of two switching band pairs require to be further studied.
	+ New indication: New DCI format or MAC-CE is required to be specified.
	+ Delay of indication: The DCI/MAC-CE will introduce delay before UE can transmit on new band, such as (3ms + k0 + k1) time delay in case of MAC-CE indication.
	+ Minimum gap of switching between two switching band pairs: The minimum gap between two uplink transmissions within different switching band pairs is required to be defined.
	+ CG-transmission issue: If a switching band pair is indicated by DCI/MAC CE to switching to another switching band pair, the issue on how to deal with the GC-PUSCH transmitted on the previous band shall be studied.

As shown in Figure 1, if current uplink transmission is occurred on switching band pair (C1,C2), and next uplink transmission is on switching band pair(C3,C4), the gap between two UL transmission is the number of symbols between T1 and T0, where the T1 is lasted symbol of uplink transmission occurred on switching band pair(C1,C2), the T0 is earliest symbol of uplink transmission occurred on switching band pair (C3,C4). The gap between two UL transmissions needs to be greater than the minimum gap of switching between two switching band pairs. |
| [9] NOK, NSB | From logical functionality perspective this can be understood as 2-stage Tx switching, where a band pair is selected from the set of configured bands as stage-1, and then the dynamic switching takes place between the selected two bands as in Rel-17 as stage-2. As the PCell uplink is designated to always carry the PUCCH this alternatively might be reduced to selecting which band is the pair for the band of the PCell.From specification compatibility perspective the above-dubbed stage-2 switching would be exactly as defined for Rel-17 with no functional difference. The new functionality would be the stage-1 switch that would need to be specified together with the transients and timelines that it carries with it. If it would be possible to not include the PCell in the band pair that the stage-1 picks, then additional specification complications would also arise.From the UE capability considerations perspective this approach may potentially simplify the cases the UE needs to be able to support, especially if the operation is constrained to always include the PCell uplink in the selected band pair in the stage-1. that the PCell uplink must always be included in the band pair that is dynamically switched. In addition, when needing to switch from a third band, and added delay of first having to change the dynamic switching band pair is required.**Observation 2:** Alt2 offers the direct compatibility with the existing definitions but requires adding a band pair selection stage and the respective transition timelines. The relation to PUCCH cell (whether the band of the PUCCH cell must always be one of the two bands selected) and the related implications would need to be clarified. Alt2 adds switching delay when compared to Alt1 for some switching cases. |
| [11] Xiaomi | Alt.2 will introduce more standard work, i.e. DCI design and MAC CE design. Especially, if 2 bands are indicated via DCI, it have lots of impacts including DCI payload, DCI budget, DCI alignment, PDCCH performance and so on. We have to go through every aspects as mentioned with very limited TU. For MAC CE, we may have more room to design as it is up to RAN2. However, limited TU is still a concern. Furthermore, additional time for MAC CE parsing would prolong the Tx switching procedure. |
| [13] CT | Alt.2 intends to reuse Rel-16/17 UL Tx switching as much as possible, and avoids the discussion on the new switching cases based on new tables and the corresponding ambiguity issues for Rel-18 UL Tx switching across more bands. To indicate 2 bands out of the 3 or 4 bands, MAC-CE signaling needs to be introduced or DCI design needs to be discussed, such as whether a new DCI field is introduced. Sending indicating signaling requires additional overhead. Whether to define the initial state after receiving the 2 bands switching signaling is another issue to be considered.When the current and previous UL transmission involve bands belonging to different indicated band pairs, the switching period for alt. 2 would have 2 components. The first component is caused by the indicated band pairs changing, which may need to consider all the bands within the previous band pair and the indicated band pair. If the UE is required to feedback confirmation information for the DCI or MAC CE signaling, it will cause additional delay, such as k0 + k1+3ms delay in case of MAC-CE. The second component results from switching within the indicated band pair if the Tx state is different from the initial state. Comparing with alt. 1 with one component switching period based on only the involved bands, the total switching period for alt.2 may be larger than alt. 1 for some cases. An example is when the current and previous UL transmission involve only two bands, but the two bands are not within the same indicated band pairs, the switching period for alt.1 may be the same as in Rel-17. However, for this case the switching period of alt.2 still consists 2 components. On another hand, when DCI or MAC-CE indicates the band pair changing, how to deal with the periodic SR/SRS or UL configured grant PUSCH on the carrier within the original band pair also needs discussion. |
| [15] CMCC | Regarding Alt.2, considering current spec has supported the 2 UL Tx switching between 2 bands, the Rel-18 Tx switching can be triggered in the form of switching between carriers/bands combinations from the 3 or 4 configured bands to reduce RAN1 spec impact. That is, the first step is selecting 2 out of 3 or 4 bands as the target band combination, which can be indicated by MAC CE or DCI. The second step is performing Tx switching among the selected 2 bands using Rel-16/Rel-17 mechanism and signalling. Dynamically indicate carriers/bands combination out of 3 or 4 candidate bands can also provide flexibility, and there is no need to re-define the mapping of Tx chains and antenna case by case even if the number of configured bands increases. |
| [16] MTK | The intention of Alt-2 and Alt-3 is to reduce the UE capability. However, these two alternatives don’t provide any UE complexity reduction compared to Alt-1 because the same switching cases are possible in the all the alternatives. The only difference between Alt-2/Alt-3 and Alt-1 is how the Tx switching is signalled and the time required to do the switching.1. ***Alt2 and Alt-3 don’t offer UE complexity reduction compared to Alt-1.***

In addition, Alt-2 and Alt-3 will create two switching gaps to move from one band to another band. As an example, for Alt-2, if the gNB indicated to the UE 2 bands (A & B) out of the 3 configured bands (A, B, & C), and later the gNB wants to switch the UE band C. The gNB will have to send a DCI or MAC-CE to enable the switching to band C (e.g., indicating bands A & C), and the UE will require time for reconfiguration (switching-gap#1) from A&B to A&C. Then the gNB send scheduling DCI to schedule transmission on band C, which will also require switching period (switching-gap#2). These two switching gaps will degrade the UL performance. Similarly, in Alt-3, two Tx switching will be required to move from one non-anchor band to another non-anchor.Also, Alt-2 requires new signalling design for DCI or MAC-CE. In contrast, Alt-1 can be supported with the existing signalling.1. ***For switching between some of the bands, Alt-2 and Alt-3 requires two switching gaps, which degrades the UL performance.*** ***Also, Alt-2 requires new signalling design for DCI or MAC-CE.***
 |
| [17] LG | In case of Alt 2, the gNB indicates 2 UL bands among 3 or 4 UL bands where Tx switching can occur only in the indicated 2 bands. By limiting the number of bands for Tx switching, this method cannot achieve UL throughput gain compared to Tx switching across 2 bands in Rel-16/17. One advantage is low UE complexity since Alt 2 does not allow all switching cases by limiting the number of bands allowed for Tx switching into two. However, this means high scheduling restriction and low performance gain would be caused even with the increased number of UL bands. For this Alt 2, the 2 bands for Tx switching can be indicated semi-statically or dynamically. If semi-static configuration is assumed, there would be no difference than Rel-17 Tx switching. If dynamic indication is assumed, how to indicate the 2 bands for Tx switching should be discussed with consideration of the indication reliability. Also, how to handle the configured UL transmission when the indicated UL bands are changed may need to be discussed. |
| [18] QC | On top of Alt. 1, Alt. 2 provides some flexibility on processing time as it allows network to indicate the switching band pairs by DCI or MAC-CE. If the indicated band pairs are from the same candidate pairs with Alt. 1, the complexity & the cost are almost same as Alt. 1. However, if the candidate band pairs are a subset of Alt. 1 and reported as UE capability, the complexity could be reduced namely. It would be good that proponents of Alt. 2 could elaborate the details on the band pair candidates.For Alt. 1 & Alt. 2, current RRC configuration may not work as there are some chance that none of the two dynamic switch bands is configured with switching period location. Take three bands switching as an example, if the RRC configuration indicates band A to take the switching period. Alt. 1 allows dynamic switching between any two bands. If the switching is between band B and C, there would be ambiguity as none of them is configured with switching period location. Alt 2 may have similar issue as the dynamic switching band pair is indicated by DCI or MAC-CE, which is much more frequent than RRC configuration.**Observation: For down-selection among three alternatives, minimize the standard efforts should be preferred. One example is which band to take the switching period,** * **Alt. 1 and Alt. 2 would require new configuration mechanism as current RRC configured switching period location may not work if none of the two dynamic switch bands is configured with switching period location.**
* **Alt. 3 could reuse current configuration mechanism with minimized efforts as the switching period could be configured on the anchor band or non-anchor band.**
 |
| [19] Apple |

|  |  |  |
| --- | --- | --- |
| **Alt 2**: Dynamic UL Tx carrier switching only across a subset of 2 bands from 3 or 4 bands | * Additional flexibility compared to Rel-16/17
* No RRC reconfiguration needed once 3 or 4 bands are configured
* Less delay to update the pair from 3 or 4 bands
* No specification impact needed to define new switching cases as Rel-16/17 switching cases can be directly applies
* Almost no to little impact in terms of UE complexity
 | * Slightly less flexibility compared to Alt 1 or same flexibility with slightly more delay to switch across 3 or bands
 |

Furthermore, details on the mechanism for Alt 2 should be further discussed. The key aspect is the signaling enhancement for selecting a sub-set of 2 bands from 3 or 4 bands. In our view, the procedure and corresponding signaling for Alt 2 can be described as follows (assuming UE will support Rel-18 UL Tx switching for 3 and 4 bands):* **Step 1**: UE reports band combination with 3 and 4 bands for Rel-18 UL Tx switching
* **Step 2**: For the reported band combinations, either network can configure the UE with a table and each row of the table indicates a pair of bands selected from the 3 or 4 configured bands or UE can report such a table
* **Step 3**: Once the table is configured, then network can indicate UE with one pair from the table
* **Step 4**: Following the indication of a pair from the table, similar procedure as defined in Rel-16/Rel-17 can be applied and switching cases between the two bands in the indicated table can be scheduled, i.e., switching is allowed only between the two bands of the indicated pair

One aspect to consider in the above steps is how to indicate UE with a pair from the table. In our view dynamic signaling should be used to provide the flexibility to have a relatively faster update of the band pair in comparison to Rel-16/17, where RRC reconfiguration is needed. However, it is not expected that the band pair would be updated with every scheduling instance, otherwise it tends to be like Alt 1. Therefore, to avoid very frequency update of band pair, but still have dynamic flexibility, MAC CE based indication of the band pair should be supported.  |
| [20] DCM | * + NW configures 3 or 4 bands for UL Tx switching via RRC signaling, and DCI or MAC-CE needs to be used to indicate 2 bands out of the configured bands prior to scheduling UL transmission on any of the 2 bands. This DCI or MAC-CE based indication of candidate bands for dynamic Tx switching is the additional procedure/feature compared with Rel-17.
	+ Even in Alt.2, supported switching cases are same as Alt.1 in some sense, i.e., UE can realize any of the cases in Figure 1/2 via 2-step procedure, such as DCI or MAC-CE indication of 2 bands followed by UL scheduling. However, the number of candidate bands for dynamic switching (i.e., based on UL scheduling) at each Tx chain can be same as Rel-17. It would mean that in Alt.2 a UE can reconfigure candidate bands at each Tx chain dynamically based on DCI or MAC-CE indication, and such reconfiguration procedure would require a certain time duration (which cannot be within switching period).
	+ Since Alt.2 requires DCI or MAC-CE indication of 2 bands prior to scheduling UL transmission on any of the 2 bands, Alt.2 has scheduling restriction or delay for band(s) currently not indicated by DCI or MAC-CE. Whether Alt.2 can provide sufficient gain over Rel-17 UL Tx switching across 2 bands should be investigated with considering the scheduling restriction or delay as well as overhead increase due to DCI or MAC-CE.

|  |  |  |
| --- | --- | --- |
| Alt.2 | * The same number of candidate bands for dynamic switching (based on UL scheduling) at each Tx chain as in Rel-17
 | * Scheduling restriction (delay) for some band(s), i.e., lower performance compared with Alt.1
* Overhead/complexity increase due to new DCI or MAC-CE indication
 |

**Observation 1: The complexity of the switching mechanism may depend on the number of candidate bands for dynamic switching at each Tx chain and/or the number of switching patterns for dynamic switching at each Tx chain.*** **All the switching cases would be supported in Alt.1/2/3, but Alt.2 requires an additional procedure (i.e., reconfiguration of 2 candidate bands for dynamic switching based on DCI or MAC-CE indication) for direct switching between specific cases, and Alt.3 has a restriction for direct switching between specific cases.**

**Observation 2: There may be no significant difference among Alt.1, 2 and 3 in terms of the number of the candidare bands for dynamic switching at each Tx chain.*** **Alt.2 allows a relaxed timeline for “dynamic switching” by requiring DCI or MAC-CE indication compared with Alt.1/3, but the number of the candidate bands for (semi-)dynamic switching at each Tx chain is same as Alt.1.**
* **Alt.3 has smaller number of candidate bands for dynamic switching at Tx chain when the Tx chain is currently associated with non-anchor band, but Alt.3 has the same number of candidate bands for dynamic switching at Tx chain when the Tx chain is currently associated with anchor band as in Alt.1.**

**Observation 3: Alt.2 and Alt.3 have scheduling restriction (delay) for some band(s) and hence the performance should be lower than that of Alt.1.** |
| [21] E/// | Alt 1 is the super set which provides full flexibility in operation and is preferred from NW operation point of view. Alt 2 and Alt 3 are proposed claiming to simplify the operation or reduce UE complexity, respectively. We discuss our understanding of Alt 2 and Alt 3 first, and the challenges and issues that we observe with these alternatives. We further explain that how Alt 1 can be updated to address the underlying concerns that in our understanding, motivated proposing alternatives 2 and 3.It is observed that in Alt 1, transition between any two states does not rely on an intermediate state or additional dynamic signalling as opposed to Alt 2 and Alt 3. This property is of high importance for finding dynamic UL Tx switching across 3 bands beneficial to use. The operation based on Alt 2 and Alt 3 imposes dependency between scheduled UL transmissions on 3 bands. Therefore, it complicates scheduling since feasibility of any scheduled transmission relies on the previous UL transmissions or transition enabler DCI/MAC-CE. The dependency is not only determinantal for the NW operation, but also for the system throughput due to error propagation in case of intermediate miss detection at UEs. If an UL grant is missed, not only a UE misses the corresponding UL transmission, but also invalidates the followed up scheduled UL transmissions. Moreover, regarding Alt 2, in addition to the negative consequences of dependent scheduling, one can clearly observe that it requires additional DCI/MAC-CE overhead for enabling state transitions.Therefore, in our view if UL Tx switching is to be supported, only operation based on Alt1 is meaningful. Any approach based on Alt 2 and Alt 3 clearly makes the promised benefits and usefulness of dynamic UL Tx switching across more than 2 bands questionable. The concerns raised towards UE complexity should properly addressed with Alt 1 framework to have a meaningful design. In our view, to support Alt 1 while addressing the claimed UE complexity, the notion of anchor band to switch a TX chain to/from, can be reflected properly in the procedure such that the relaxed UE complexity does not result in scheduling complexity. 1. UL Tx switching across 3 or 4 bands design based on Alt 2 and Alt 3 results in scheduling dependency and error propagation. Any design based on Alt 2 and Alt 3 makes the promised benefits and usefulness of dynamic UL Tx switching across more than 2 bands questionable.
2. If UL Tx switching across 3 or 4 bands is supported, only operation based on Alt1 that properly addresses UE complexity is meaningful.

**To support Alt 1 while addressing the claimed UE complexity, the notion of anchor band to switch a TX chain to/from, can be reflected properly in the procedure such that the relaxed UE complexity does not result in scheduling complexity.** |
| [22] Google | Alt-2 is proposed to reuse Rel. 17 mechanisms as much as possible. When the base station indicates (e.g., by DCI or MAC CE) 2 bands out of 3 or 4 configured bands for UL Tx switching, the UE can follow procedures in Rel. 17 to perform antenna states transition in only 3 antenna states, 1T+1T, 0T+2T, and 2T+0T. In this case, this method can respectively reduce 80% and 93% of antenna state transitions in 3 and 4 bands scenarios (comparing to Alt-1). However, the cost is that new control signalling (e.g., by DCI or MAC CE) has to be specified. Whether the gain from applying UL Tx switching can compensate the increased control overheads or not should be further clarified.From our perspective, although antenna state transitions can be reduced tremendously by applying additional switching rules (e.g., Alt-2 and Alt-3) to the UE, the Tx chains still have to be capable of switching among these antennas. In this regard, we don’t see much complexity reduction by applying additional switching rules to UL Tx switching in 3 and 4 bands. On the other hand, the current RAN1 spec can apply to Alt-1 directly, except for the antenna states to antenna port ambiguity case resolution, thus the spec impact is limited.**Observation 2: Alt-2 can respectively reduce 80% and 93% of antenna state transitions in 3 and 4 bands scenarios (comparing to Alt-1). Whether or not the gain acquired by applying UL Tx switching in 3 and 4 bands can compensate the introduced overhead (e.g., DCI and MAC CE) should be further clarified.****Observation 4: Although applying additional switching rules to the UE can reduce the number of antenna state transitions, the Tx chains still have to be capable of switching among these antennas. Thus, the complexity reduced by introducing Alt-2 and Alt-3 is unclear to us.** |

Based on above, the situation can be summarized as below.

### Summary 3.2

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| --- |
| * Alt.2: NW indicates 2 bands out of the configured bands (3 or 4 bands) via DCI or MAC-CE, and dynamic Tx carrier switching between indicated bands is same as Rel-17
	+ Scheduling restriction and long UL interruption/delay due to band pair switching e.g., at least 3 ms processing time is necessary for MAC-CE processing [1, 2, 4, 7, 8, 9, 11, 13, 16, 17, 20, 21]
		- Performance is almost same with Alt.1 since band pair switching is not frequent [2, 6, 19]
	+ Some additional spec effort e.g., defining band pair switching cases, initial Tx state, RAN2 effort on new MAC-CE or RAN1 effort for new DCI [4, 7, 8, 9, 11, 13, 17, 20, 22]
	+ RAN4 requirements and RAN2 signaling framework for band pair can be reused [2, 4, 8, 9, 15, 19, 22]
	+ Handling of CG-transmission/HARQ-retransmission/PUCCH-transmission/periodic SR/SRS on band outside the indicated band pair needs to be studied [1, 8, 9, 13, 17]
	+ Same switching cases with Alt.1, complexity reduction is unclear [16, 18, 20, 22]
	+ Switching period can be short after band pair indication [2]
	+ DCI based band pair indication can be in scheduling DCI with new field [2]
	+ Current RRC configuration on switching period location may not work [18]
 |

The moderator would like to ask companies to provide feedback if any on the above summary.

|  |  |
| --- | --- |
| Company | Comment |
|  |  |
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## 3.3 Views on Alt.3: One anchor band is selected among configured bands (3 or 4 bands), and dynamic Tx carrier switching can be performed only from the anchor band to a non-anchor band and from a non-anchor band to the anchor band

In contributions, following observations were made regarding Alt.3.

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| --- | --- |
| [1] HW, HiSi | It is interesting to check whether anchor band proposed in Alt 3 can relief any burden of UE memory discussed above. In Alt 3, one anchor band is selected among configured bands and switch restrictions are defined based on anchor band. In this case, there is also transmission gap that cannot be scheduled for UL transmission because of loading another non-anchor band. For example, band B is an anchor band, when UL Tx switching from band A&B to band B&C, the sum of switch-from bands and switch-to bands is more than two and UE should flush the memory of band A and then reload it with the new information for band C after the transmissions on band A&B are completed.For Alt 3, as discussed in [3], the motivation of defining an anchor band for Option 1 is to reduce UE memory. In another word, the size of UE memory is limited and memory sharing is also needed in Alt 3. For example, as shown in Figure 10, the anchor band is band B, when 2nd UL Tx switching from band B to band C is triggered, since essential baseband and RF information for UL transmissions on band C is not pre-stored in the memory, the UE needs to flush the memory of band A and then reload it with the new information for band C before the UE can use this information to transmit data on band C starting at the 2nd UL Tx switching. Therefore, **the mechanisms of UE memory sharing are also needed for the Alt 3**.Compared with Alt 3, Alt 1 obtains up to 8.5%, 12% and 14.2% uplink average UPT gain at 35u, 140us and 210us switching period, respectively. The reason is that there are more switching restrictions in Alt 3.***Observation 6:*** *Alt 3 has worse performance than Alt 1 due to scheduling restrictions.* |
| [2] ZTE | * Alt.3 is not an independent mechanism, it has to be bundled with Alt.1 or Alt.2. From our understanding, Alt.3 is a potential way to reduce the implementation complexity instead of a complete solution.
* Introducing one anchor band (as Alt.3). This could be directly applied for Alt.1 and Alt.2. For example, in case band combination A+B+C with anchor band B: For Alt.1, switching between band A and C is not supported; For Alt.2, band pair A+C is not supported. This is similar as limiting the number of supported band pairs.

***Proposal 3****: Further discuss the following methods to reduce implementation complexity.** *Limiting the number of bands supporting 2-port.*
* *Limiting the number of supported band pairs.*
* *Limiting one anchor band as Alt.3.*
* *Allowing HW resources (e.g., cache) switching between band pairs together with UL Tx switching.*
 |
| [4] vivo | For Alt.3, as the anchor band is the “anchor” during Tx switching, it is not expected to be changed frequently, i.e., probably be configured by RRC. Unfortunately, some switching cases already supported in Rel-16/Rel-17 may not be allowed. As shown in Figure 1, 2T-2T switching from non-anchor band B to non-anchor band C is not allowed. Furthermore, if there is a need to switch from one non-anchor band to another non-anchor band, multi-shot switching with anchor-relay is inevitable. For example, if there was a preceding transmission on non-anchor band B, when traffic arrives on non-anchor band C, UE has to switch from non-anchor band B to anchor band A first, then switch to non-anchor band C as shown in Figure 1. Multi-shot Tx switching may result in increased DCI overhead, larger latency, and lower efficiency. |
| [6] FJT | The benefit of Alt-1 is the flexibility, and the maximum performance gain can be achieved by this flexibility while the highest complexity is required to Ues. Meanwhile, Alt-2 can achieve the least functional change on top Rel-17 Tx switching. Alt-3 would be helpful from UE implementation perspective because UE is not required to manage many switching combinations. In our understanding, the gain by this technology is derived by the efficient use of Tx chain (i.e. unused Tx chain in a carrier with DL slot is switched to a carrier with UL slot) as described in section 2.1. Therefore, the switching pattern is something predetermined, and we don’t think the scheduling restriction introduced by Alt-2 or Alt-3 brings severe performance degradation. Beside the specification impact and UE complexity, we believe all the alternatives will work. However, Alt-3 based solution would be the good compromise considering the UE complexity reduction and flexibility.**Observation 2:*** *No additional restriction is necessary to reduce UE complexity if Alt-3 above is supported*
 |
| [7] OPPO | For Alt 3, mechanism is closely related with hardware implementation and it cannot provide benefit for any implementation solution. And it increases switch latency due to switch procedure includes band-to-anchor band and anchor band-to-band and each step requires one switch period. |
| [8] CATT | * Advantage: the complexity of gNB/UE can be reduced,
	+ The number of supported TX switching cases is redueced.
	+ There is no ambiguity issue.
* Disadvantage: it will impose additional restriction on uplink scheduling of gNB.
	+ TX switching can only be performed between anchor carrier and non-anchor carriers.
	+ The anchor carrier transmission shall be triggered before TX switching between two non-anchor carriers.

As shown in above Figure 2, if current uplink transmission is occurred on carrier-2 and carrier-3, and next uplink transmission is on carrier-4. Because the UL Tx switching cannot perform between carrier-4 and carrier-3. The gNB should perform uplink scheduling on carrier 3 first, and only after additional UL TX switching, the UE can be scheduled to transmit signals on carrier 4. Additional UL TX switching on anchor carrier will cause unnecessary delay. |
| [9] NOK, NSB | This alternative is somewhat less clear than the Alt1 and Alt2. First question is how the anchor band selection is done. If the anchor band is to always contain the Pcell, then the Alt3 would seem to be a special case of Alt1 where on 1+1 transmission case the band of the Pcell is always one of two bands, and whenever a non-anchor band is to begin transmission, the Tx chain needed to be on the anchor band first. However, this rotation behaviour, if actually part of this alternative, is not very attractive from the system operations perspective. If, the anchor band is not tied to the Pcell band, then it leaves the question on PUCCH handling to be answered as the UE might not be able to transmit PUCCH when needed. It is difficult to assess the specification implications before further discussing the specifics of this alternative. If the correct interpretation of this alternative is that if Band A is the anchor, then moving a Tx from Band B to Band C is only possible by rotating it first through Band A, then all the switching cases reduce to those in Rel-17, which should simplify the specification effort. It should be noted thought that there is an additional transitory delay when needing to switch form Band B to Band C, if that requires that the transmit chain has to be rotated from Band B to Band C via the anchor band A.**Observation 3:** Alt3 seems to be a special case of Alt1 where a subset of transitions only are allowed. The question on how the anchor cell is selected and, as with Alt2, the relation to PUCCH cell (whether the band of the PUCCH cell must always be the anchor) and the related implications would need to be clarified. Alt3 adds switching delay when compared to Alt1 for some switching cases. |
| [11] Xiaomi | Alt.3 would double the time requested by switching period as UL band switching has to be connected by an anchor band. How to define/determine the anchor band needs additional standard works. |
| [13] CT | Alt.3 selects one anchor band among the 3 or 4 bands aiming to simplify the UE implementation for Rel-18 Tx switching. However, whether the UE’s memory and processing capability resource could actually be simplified by this alternative is not clear. This alternative limits the flexibility for one switching time and would result in more switching times with possible longer total switching period. For example, when Tx switching is performed across 3 bands and the first band is the anchor band, if 2Tx on the second band needs to switch to the third band, it should switch to the first band firstly and then switch from the first band to the third band. The switching period takes the two switching times into account which may be longer than directly switching from the second to the third band. |
| [15] CMCC | While for Alt.3, as the Tx switching can only be performed between the selected anchor band and a non-anchor band, when there are 3 or 4 bands configured for UL Tx switching, the Tx switching between two non-anchor band will be limited. This will affect the flexibility of UL Tx switching considering the motivation is to ensure available scattered spectrum bands can be utilized in a more spectral/power efficient and flexible manner.  |
| [16] MTK | The intention of Alt-2 and Alt-3 is to reduce the UE capability. However, these two alternatives don’t provide any UE complexity reduction compared to Alt-1 because the same switching cases are possible in the all the alternatives. The only difference between Alt-2/Alt-3 and Alt-1 is how the Tx switching is signalled and the time required to do the switching.1. ***Alt2 and Alt-3 don’t offer UE complexity reduction compared to Alt-1.***

In addition, Alt-2 and Alt-3 will create two switching gaps to move from one band to another band. As an example, for Alt-2, if the gNB indicated to the UE 2 bands (A & B) out of the 3 configured bands (A, B, & C), and later the gNB wants to switch the UE band C. The gNB will have to send a DCI or MAC-CE to enable the switching to band C (e.g., indicating bands A & C), and the UE will require time for reconfiguration (switching-gap#1) from A&B to A&C. Then the gNB send scheduling DCI to schedule transmission on band C, which will also require switching period (switching-gap#2). These two switching gaps will degrade the UL performance. Similarly, in Alt-3, two Tx switching will be required to move from one non-anchor band to another non-anchor.1. ***For switching between some of the bands, Alt-2 and Alt-3 requires two switching gaps, which degrades the UL performance.*** ***Also, Alt-2 requires new signalling design for DCI or MAC-CE.***
 |
| [17] LG | In case of Alt 3, it can be understood as a method of allowing UL Tx switching only in a specific band (a.k.a. anchor band) or a band pair including the anchor band, in order to reduce the number of cases requiring Tx switching. However, similar to Alt 2, large scheduling restriction might be expected, which would limit the performance gain obtainable by increasing the number of UL bands. In addition, when the anchor band (or its paired non-anchor band) is dynamically indicated, it may need to discuss the method of indicating the anchor band and how to handle the configured UL transmission when the anchor band (or non-anchor band) is changed may need to be discussed. |
| [18] QC | Alt. 3 defines an anchor band which is capable of switching to any other bands (aka non-anchor bands). To reduce the RF searching complexity, we prefer to considering fixing one Tx chain on anchor band and leave another Tx flexibly switching between anchor and non-anchor bands. Furthermore, to reduce the memory cost, we suggest to only allow direct switching between anchor and non-anchor band, the two non-anchor bands switching could use anchor band as a bridge. Below we want to share our views on the implementation complexity which comes from two aspects – Memory & RF aspects. We also analyse the three alternatives accordingly. Memory* The memory for switching complexity is consumed by RF components for Tx switching. To optimize the fast switching the UE needs larger memory to store the RF configurations, status and some data before and after switching. The memory is needed \*for each switching band pair\*, \*not for each band\*.
* Alt. 1 has the most switching pairs, even for SwitchedUL (Option 1), and thus requires a large among of memory. The switching pairs for Option 1 could be with 12 band pairs (A->B, B->A, A->C, C->A, A->D, D->A, B->C, C->B, B->D, D->B, C->D, D->C). Alt. 3 SwitchedUL only have 6 band pairs (A->B, B->A, A->C, C->A, A->D, D->A). Unfortunately, this memory is usually dedicated for certain band pair, which could not be recycled and shared by different band pairs even the switching would be in different time. Alt. 2 has similar memory requirements as it needs to be prepared as network might indicate any band pairs in next MAC-CE or DCI. The only advantage of MAC-CE based indication is more preparation time is allowed compared to Alt. 1.

RF* To further reduce the complexity, for Alt. 3 we prefer no direct switch between two non-anchor bands. For example, if the 1st state is Tx at band A+B (A as anchor), and target case is Tx at band A+C, the Tx on B needs to go back to A and then to C which means switching only between anchor and non-anchor bands.
	+ **Note that when we say ‘go back to A’, we don’t mean that an actual transmission needs to be scheduled and performed in band A. Rather, we mean simply that any B 🡪 C switch would have to allow enough time in principle to go through an RF state switch sequence of B 🡪 A 🡪 C, irrespective of whether transmission in A is involved or not.**
* To avoid the required resource increased exponentially if both Tx chains are capable of dynamic switch, we think there should be no restriction on the UEs choice of MIMO capability on any of the bands/CCs involved in the Rel-18 UL Tx switching band combination. We prefer Alt. 3 only allow one Tx chain switching flexibly, some cases like Tx at band B+C, C+D would be precluded as it requires both Tx chains on anchor band switches to two different non-anchor bands.
* Meanwhile, as the switching bands increase, the UE needs to monitor more switching decisions we propose to avoid frequent scheduling within 14 consecutive symbols.

Alt. 3 defines an anchor band in the switching band combination. For any RF state switch, either the switch to or switch from carrier/band must be the anchor band. The switching period could be configured on the anchor band or non-anchor band, and the current switching period location configuration mechanism would work properly.**Observation: For down-selection among three alternatives, minimize the standard efforts should be preferred. One example is which band to take the switching period,** * **Alt. 1 and Alt. 2 would require new configuration mechanism as current RRC configured switching period location may not work if none of the two dynamic switch bands is configured with switching period location.**
* **Alt. 3 could reuse current configuration mechanism with minimized efforts as the switching period could be configured on the anchor band or non-anchor band.**
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| [19] Apple |

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| **Alt 3**: Dynamic UL Tx carrier switching only from or to an anchor band | * Reduced number of switching cases compared to Alt 1
 | * Still considerable specification impact compared to Alt 2
* New switching cases need to be defined compared to Rel-16/17 or Alt 2
* Further specification effort to determine criteria, assign and/or update anchor band
 |

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| [20] DCM | * + NW configures 3 or 4 bands for UL Tx switching and one anchor band out of the configured bands via RRC signaling. In Alt.3, dynamic switching between non-anchor bands is not available. Assuming that such restriction is applied to each Tx chain individually, supported switching cases are same as Alt.1/2 in some sense, i.e., UE can realize any of the cases in Figure 1/2. For example, when both of two Tx chains are currently associated with anchor band (e.g., band A+A), each Tx chain can be switched to any non-anchor band and hence any of cases in Figure 1/2 can be realized (e.g., band B+B, C+C, B+C). However, the number of candidate bands for dynamic switching at each Tx chain is different depending on the current switching case as below.
		- When a Tx chain is currently associated with non-anchor band, the number of candidate bands for dynamic switching at the Tx chain is 2, i.e., current non-anchor band and anchor band.
		- When a Tx chain is currently associated with anchor band, the number of candidate bands for dynamic switching at the Tx chain is 3 or 4, i.e., anchor band and any of non-anchor band.
	+ In Alt.3, since the switching pattern is restricted to only between anchor and non-anchor bands, the number of switching patterns for dynamic switching at each Tx chain can be smaller than that for Alt.1/2 as below.
		- In Alt.1, the number of switching patterns for dynamic switching is 6 in case of 3 bands (A to B, A to C, B to C and reversed patterns) and 12 in case of 4 bands (A to B, A to C, A to D, B to C, B to D, C to D and reversed patterns).
		- In Alt.2, the number of switching patterns for dynamic switching (based on UL scheduling) is 2, while the number of switching patterns for semi-dynamic switching (based on DCI or MAC-CE + UL scheduling) is same as Alt.1.
		- In Alt.3, the number of switching patterns for dynamic switching is 4 in case of 3 bands (A to B, A to C and reversed patterns when A is anchor) and 6 in case of 4 bands (A to B, A to C, A to D and reversed patterns when A is anchor).
	+ Since Alt.3 has restrictions on the switching patterns, Alt.3 has scheduling restriction or delay for non-anchor band(s). Whether Alt.3 can provide sufficient gain over Rel-17 UL Tx switching across 2 bands should be investigated with considering the scheduling restriction or delay.

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| Alt.3 | * The smaller number of switching patterns for dynamic switching at each Tx chain compared with Alt.1
 | * Scheduling restriction (delay) for non-anchor band(s), i.e., lower performance compared with Alt.1
 |

**Observation 1: The complexity of the switching mechanism may depend on the number of candidate bands for dynamic switching at each Tx chain and/or the number of switching patterns for dynamic switching at each Tx chain.*** **All the switching cases would be supported in Alt.1/2/3, but Alt.2 requires an additional procedure (i.e., reconfiguration of 2 candidate bands for dynamic switching based on DCI or MAC-CE indication) for direct switching between specific cases, and Alt.3 has a restriction for direct switching between specific cases.**

**Observation 2: There may be no significant difference among Alt.1, 2 and 3 in terms of the number of the candidare bands for dynamic switching at each Tx chain.*** **Alt.2 allows a relaxed timeline for “dynamic switching” by requiring DCI or MAC-CE indication compared with Alt.1/3, but the number of the candidate bands for (semi-)dynamic switching at each Tx chain is same as Alt.1.**
* **Alt.3 has smaller number of candidate bands for dynamic switching at Tx chain when the Tx chain is currently associated with non-anchor band, but Alt.3 has the same number of candidate bands for dynamic switching at Tx chain when the Tx chain is currently associated with anchor band as in Alt.1.**

**Observation 3: Alt.2 and Alt.3 have scheduling restriction (delay) for some band(s) and hence the performance should be lower than that of Alt.1.** |
| [21] E/// | Alt 1 is the super set which provides full flexibility in operation and is preferred from NW operation point of view. Alt 2 and Alt 3 are proposed claiming to simplify the operation or reduce UE complexity, respectively. We discuss our understanding of Alt 2 and Alt 3 first, and the challenges and issues that we observe with these alternatives. We further explain that how Alt 1 can be updated to address the underlying concerns that in our understanding, motivated proposing alternatives 2 and 3.It is observed that in Alt 1, transition between any two states does not rely on an intermediate state or additional dynamic signalling as opposed to Alt 2 and Alt 3. This property is of high importance for finding dynamic UL Tx switching across 3 bands beneficial to use. The operation based on Alt 2 and Alt 3 imposes dependency between scheduled UL transmissions on 3 bands. Therefore, it complicates scheduling since feasibility of any scheduled transmission relies on the previous UL transmissions or transition enabler DCI/MAC-CE. The dependency is not only determinantal for the NW operation, but also for the system throughput due to error propagation in case of intermediate miss detection at UEs. If an UL grant is missed, not only a UE misses the corresponding UL transmission, but also invalidates the followed up scheduled UL transmissions. Moreover, regarding Alt 2, in addition to the negative consequences of dependent scheduling, one can clearly observe that it requires additional DCI/MAC-CE overhead for enabling state transitions.Therefore, in our view if UL Tx switching is to be supported, only operation based on Alt1 is meaningful. Any approach based on Alt 2 and Alt 3 clearly makes the promised benefits and usefulness of dynamic UL Tx switching across more than 2 bands questionable. The concerns raised towards UE complexity should properly addressed with Alt 1 framework to have a meaningful design. In our view, to support Alt 1 while addressing the claimed UE complexity, the notion of anchor band to switch a TX chain to/from, can be reflected properly in the procedure such that the relaxed UE complexity does not result in scheduling complexity. 1. UL Tx switching across 3 or 4 bands design based on Alt 2 and Alt 3 results in scheduling dependency and error propagation. Any design based on Alt 2 and Alt 3 makes the promised benefits and usefulness of dynamic UL Tx switching across more than 2 bands questionable.
2. If UL Tx switching across 3 or 4 bands is supported, only operation based on Alt1 that properly addresses UE complexity is meaningful.

**To support Alt 1 while addressing the claimed UE complexity, the notion of anchor band to switch a TX chain to/from, can be reflected properly in the procedure such that the relaxed UE complexity does not result in scheduling complexity.** |
| [22] Google | Regarding Alt-3, the method limits some antenna state transitions paths by indicating an anchor band, and Tx chains can only switch to or from the indicated anchor band, which can respectively reduce 33% and 69% antenna state transitions in 3 and 4 band scenarios (comparing to Alt-1). One issue should be addressed is that if a UE does not support 2T transmission in any band, should the base station indicate 1 or 2 anchor bands to the UE? From our perspective, although antenna state transitions can be reduced tremendously by applying additional switching rules (e.g., Alt-2 and Alt-3) to the UE, the Tx chains still have to be capable of switching among these antennas. In this regard, we don’t see much complexity reduction by applying additional switching rules to UL Tx switching in 3 and 4 bands. On the other hand, the current RAN1 spec can apply to Alt-1 directly, except for the antenna states to antenna port ambiguity case resolution, thus the spec impact is limited.**Observation 3: Alt-3 can respectively reduce 33% and 69% antenna state transitions in 3 and 4 bands scenarios (comparing to Alt-1). The issue that if 2T transmission is not supported by the UE should be addressed. For example, whether the base station should indicate 1 or 2 anchor bands to the UE?****Observation 4: Although applying additional switching rules to the UE can reduce the number of antenna state transitions, the Tx chains still have to be capable of switching among these antennas. Thus, the complexity reduced by introducing Alt-2 and Alt-3 is unclear to us.** |

Based on above, the situation can be summarized as below.

### Summary 3.3

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| * Alt.3: One anchor band is selected among configured bands (3 or 4 bands), and dynamic Tx carrier switching can be performed only from the anchor band to a non-anchor band and from a non-anchor band to the anchor band
	+ Less performance than Alt.1 due to scheduling restrictions or 2-step switching [1, 4, 8, 9, 11, 13, 15, 16, 17, 20, 21]
		- Performance degradation may not be so severe [6]
	+ This may be bundled with Alt.1 or 2 to reduce implementation complexity [2, 6, 9, 18]
		- Number of candidate bands for dynamic switching or required UE memory size is same as Alt.1, and complexity reduction is unclear [1, 13, 16, 20, 22]
		- Required number of UE memories dedicated to each band pair or number of switching patterns is reduced [18, 20, 22]
	+ Some additional spec efforts, e.g., how to select anchor band [9, 11, 17, 19]
	+ Less number of supported Tx switching cases [8, 18, 19]
	+ Some switching cases already supported in Rel-17 may not be allowed [4]
	+ No ambiguity issue [8]
 |

The moderator would like to ask companies to provide feedback if any on the above summary.

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| Company | Comment |
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## 3.4 Proposals for the down-selection

In contributions, following proposals were made for the down-selection.

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| [1] HW, HiSi | ***Proposal 1:*** *For dynamic UL Tx switching across 3 or 4 bands, in order to reduce UE complexity, the sharing of UE memory across bands and its required flushing & reloading time should be taken into account.****Proposal 3:*** *For dynamic UL Tx switching across 3 or 4 bands, Alt 1 is adopted, i.e., an UL Tx switching can occur between any supported switching cases and is triggered by a UL grant or RRC-configured UL transmissions.* |
| [2] ZTE | ***Proposal 2****: To strive for a common design for 3 bands and 4 bands and strive for an extensible solution for UL Tx switching, Alt.2 is supported for Rel-18 UL Tx switching, where network can indicate two bands (or indicate the cells within two bands) for subsequent transmission via MAC-CE or DCI.* |
| [3] SPRD | 1. ***Support Alt.1 with complexity reduction methods: Dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission***
 |
| [4] vivo | **Proposal 1: For the possible mechanisms for dynamic Tx carrier switching across the configured bands, alt.1 should be supported.** |
| [5] Sony | **Proposal 1: We propose to go ahead with Alt 1, with a higher layer switching rule indication to enable the UE to do autonomous switching among 3 or 4 carriers.**  |
| [6] FJT | **Proposal 1:*** *If dynamic Tx carrier switching scheme is specified, adopt Alt-3 with the following understanding:*
	+ *UE capability is introduced to report the available combinations of anchor and non-anchor band for a UE*
	+ *Anchor and non-anchor relationship among CCs is configured by gNB*
		- *FFS: the details of anchor/non-anchor relationship*
	+ *Actual UL carrier switching is performed by UL grant and/or RRC configuration for UL transmission*
		- *Carriers with anchor and non-anchor relationship cannot be scheduled simultaneously, i.e. gNB scheduler shall avoid such situations.*
 |
| [7] OPPO | ***Proposal 1: Alt 1, i.e. Dynamic Tx carrier switching across all the supported switching cases, is preferred due to less spec effort and low switch latency.*** |
| [8] CATT | **Proposal 2：For dynamic Tx carrier switching across the configured 3/4 bands, Alt.1 is preferred*** **Alt.1: Dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission.**
 |
| [9] NOK, NSB | **Proposal 1:**1. **Take the Alt1 as the working assumption for way forward**
2. **Clarify Alt2 relation to PUCCH cell, and whether it offers a concrete simplification (spec or implementation) over Alt1**
3. **Clarify Alt3 relation to anchor cell selection and relation to PUCCH cell, and whether it offers any concrete simplification (spec or implementation) over Alt1**
 |
| [11] Xiaomi | ***Proposal 2: If UL Tx switching across more than 2 bands is supported, Alt.1 should be supported.**** ***Alt.1: Dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission***
 |
| [13] CT | **Proposal 2: For Rel-18 UL Tx switching across up to 3 or 4 bands, dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission.** |
| [14] SS | **Proposal 5:** *Rel-18 UL Tx switching supports Alt.1: dynamic Tx carrier switching across all the supported switching cases by the UE and based on UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission.* |
| [15] CMCC | **Proposal 1. To support the UL Tx switching across 3 and 4 bands, the following enhancement of switching mechanism can be further studied.*** **Alt.1. Dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission.**
* **Alt.2. Dynamically indicate carriers/bands combination out of 3 or 4 candidate bands for UL Tx switching by signalling, e.g., MAC CE, DCI, and reuse Rel-17 UL Tx switching mechanism among carriers/bands combination.**
 |
| [16] MTK | 1. ***Support Alt.1 for R18 UL Tx switching between 3 or 4 bands.***
 |
| [17] LG | **Proposal #1: Support Alt 1 as the baseline mechanism of Rel-18 UL Tx switching, which is the only way to maximize performance gain by increasing the number of configured bands compared to Rel-17 UL Tx switching.**  |
| [18] QC | **Proposal 3: For inter-band UL CA Option 1 and Option 2 without SUL, adopt following for UL Tx switching among 3 or 4 bands.*** **Identify an anchor band in the switching band combination. For any RF state switch, either the switch-to or switch-from carrier/band must be the anchor band, and no direct switch between non-anchor bands.**
* **Indirect switch between non-anchor bands is allowed.**
	+ **Indirect switch means that the gap time is increased, which in principle allows going through a two-step RF state switch sequence {non-anchor 🡪 anchor 🡪 other non-anchor}, irrespective of whether transmission in anchor in the middle state is performed or not.**
* **No restriction on the UEs choice of MIMO capability on any of the bands/CCs involved in the Rel-18 UL Tx switching band combination.**
* **After one RF state switch, the next RF state switch must occur after 14 symbols or later.**
	+ **Which SCS assumed for symbol duration is TBD.**
 |
| [19] Apple | ***Proposal 1: RAN1 should agree to support Alt 2 for enhancing dynamic UL Tx switching by dynamically activating only a pair of bands from the 3 or 4 configured bands for Rel-18 dynamic UL Tx switching, if 3 or 4 bands are agreed to be supported******Proposal 2: RAN1 should consider the following procedure for Alt 2 based UL Tx switching mechanism in Rel-18, if 3 or 4 bands are agreed to be supported:**** ***Step 1: UE reports band combination with 3 and 4 bands for Rel-18 UL Tx switching***
* ***Step 2: For the reported band combinations, either network can configure the UE with a table and each row of the table indicates a pair of bands selected from the 3 or 4 configured bands or UE can report such a table***
* ***Step 3: Once the table is configured, then network can indicate UE with one pair from the table***
* ***Step 4: Following the indication of a pair from the table, similar procedure as defined in Rel-16/Rel-17 can be applied and switching cases between the two bands in the indicated table can be scheduled, i.e., switching is allowed only between the two bands of the indicated pair***

***Proposal 3: RAN1 should consider supporting MAC CE based indication of a band pair from the 3 or 4 configured bands for Alt 2 based UL Tx switching mechanism in Rel-18*** |
| [20] DCM | **Proposal 1:*** **Alt 1 should be considered as the baseline mechanism for Rel-18 UL Tx switching, while some mechanisms to reduce the complexity (e.g., to reduce the number of supported switching patterns/cases or transmission configurations, to relax the timeline for dynamic switching, etc.) should be considered.**
 |
| [21] E/// | 1. Dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission (i.e. Alt 1).
2. Apply the following procedures for dynamic UL Tx switching across 3 or 4 bands:
	* 1. Indicate N band(s) among 3 or 4 bands are configured as anchor band(s).
			1. N = 1 for dynamic UL TX switching across 3 bands
			2. N = 2 for dynamic UL TX switching across 4 bands (FFS N=1)
		2. For an indicated UL transmission, if after the preceding UL transmission, the UE is under operation state that is different from the ending state, and if none of the bands in the ending and operation states are an anchor band, the UE expects that the indicated UL transmission to occur after at least a gap of duration X after the end of the proceeding transmission.
			1. Note: *Operation state* refers to the state of Tx chains on two bands before an indicated UL transmission
			2. Note: *Ending state* refers to the state of Tx chains on two bands after transmission of an indicated UL transmission
			3. FSS on X (e.g. slot duration corresponding to the band w largest SCS)
 |
| [22] Google | **Proposal 1: Support Alt-1, dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission. The complexity reduction is left to UE implementation and UE capability reporting.** |

Based on above, the situation can be summarized as below.

### Summary 3.4

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| * Support Alt.1 (with some complexity reduction method)
	+ [1], [3], [4], [5], [7], [8], [9] (as WA), [11], [13], [14], [15] (Alt.1 or 2), [16], [17], [20], [21], [22]
		- With allowing UE supports of 2 ports transmission only on some or none of bands (4.2): [14]
		- With allowing UE to have more preparation procedure time for specific switching cases/patterns (4.3): [1], [20], [21]
		- With defining prioritization rules between uplink carriers (4.5): [5]
* Support Alt.2
	+ [2], [15] (Alt.1 or 2), [19] (MAC-CE based)
* Support Alt.3
	+ [6], [18] (with allowing UE supports of 2 ports transmission only on some or none of bands)
 |

There is majority support on Alt.1 while many of Alt.1 supporting companies also propose to apply some complexity reduction scheme to Alt.1.

The moderator would like to ask companies to provide feedback if any on the above summary and following potential FL proposal.

### **Proposed working assumption 3.4**

* If Rel-18 UL Tx switching is supported, following switching mechanism is considered as baseline for the Rel-18 UL Tx switching across 3 or 4 bands, and complexity reduction schemes should be further studied for the mechanism
	+ Alt.1: Dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission

|  |  |
| --- | --- |
| Company | Comment |
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1. Discussions on the proposals to address the concern on UE/gNB complexity increase and/or scheduling restriction

According to the following observation made at the last RAN1 meeting, companies provided their investigation results and proposals in contributions. In this section, companies’ observations/proposals are summarized.

|  |
| --- |
| **RAN1 Observation**Following proposals to address the concern on UE/gNB complexity increase or scheduling restriction due to UL Tx switching across larger number of bands compared with Rel-16/17 are identified in contributions submitted at RAN1#109-e, and companies are encouraged to investigate pros and cons of the proposals so that one or some of them may be down-selected after the down-selection of the mechanism for dynamic Tx carrier switching across the configured bands* UE can report the supports of only some of concurrent UL cases (combinations of 2 bands for concurrent UL transmissions)
* Switching across 0/1/2 ports is supported only for 2 configured bands out of 3 or 4 configured bands and other bands support switching across 0/1 port only
* Only switching across 0/1 port is supported across all configured bands when 3 or 4 bands are configured
* Prioritization rules between uplink carriers are specified
* No restriction on the UEs choice of MIMO capability on any of the bands/CCs involved in the UL Tx switching band combination is introduced
* After one RF state switch, the next RF state switch must occur after 14 symbols or later (FFS: which SCS is assumed for the symbol duration)
* Note: Other solutions are not precluded
* Note: each proposal assumes certain mechanism for dynamic Tx carrier switching across the configured bands, and hence some or all of the proposals may not be necessary depending on the down selection of the mechanism for dynamic Tx carrier switching across the configured bands
 |

## 4.1 Allowing UE supports of only some of concurrent UL cases (combinations of 2 bands for concurrent UL transmissions) for Inter-band CA Option 2 (dual UL)

In contributions, following proposals were made for allowing UE supports of only some of concurrent UL cases (combinations of 2 bands for concurrent UL transmissions) for Inter-band CA Option 2 (dual UL).

|  |  |
| --- | --- |
| [2] ZTE | * Limiting the number of supported band pairs. This could be directly applied for Alt.2. However, UE has to support band pairs that cover each band at least once, otherwise it is a fake Rel-18 UL Tx switching UE. For example, if UE indicates support of band combination A+B+C for Rel-18 UL Tx switching, UE is not allowed to only indicate support of band pair A+B since band C is not included in any band pair. Without this, UE has to support all the possible band pairs of one band combination.

***Proposal 3****: Further discuss the following methods to reduce implementation complexity.** *Limiting the number of bands supporting 2-port.*
* *Limiting the number of supported band pairs.*
* *Limiting one anchor band as Alt.3.*
* *Allowing HW resources (e.g., cache) switching between band pairs together with UL Tx switching.*
 |
| [3] SPRD | For UE can report the supports of **only some of concurrent UL cases** (combinations of 2 bands for concurrent UL transmissions), it is a good solution to reduce complexity. For example, the following table shows an example that UE can support concurrent UL transmissions over Band1 and Band2, but cannot over Band1 and Band3, or Band2 and Band3. Then the two antenna ports combination for UL transmission {1P+0P+1P, 0P+1P+1P} cannot be used for Table 2. Thus, two UL switching states cannot be scheduled by gNB, and UE does not expect such scheduling or configuration. Then, UE can support less switching cases, especially some high implementation complexity switching cases. Thus, only some of concurrent UL cases is a good choice.1. ***At least the following can be studied further for Rel-18 UL Tx switching together with Alt1.***
* ***UE can report the supports of only some of concurrent UL cases (combinations of 2 bands for concurrent UL transmissions)***
* ***Switching across 0/1/2 ports is supported only for 2 configured bands out of 3 or 4 configured bands and other bands support switching across 0/1 port only***
* ***Only switching across 0/1 port is supported across all configured bands when 3 or 4 bands are configured***
1. ***UE capability can be used together with the above complexity reduction methods.***
 |
| [7] OPPO | Considering that simultaneous transmission on the two bands for some cases, supporting switching between all these cases could be challenging for most of the Ues. Hence, it is necessary to allow UE to report which band combinations are supported for simultaneous transmission or Tx switch. Study on supported band combinations for Tx switch can be started in RAN 4. In addition, combination of SUL band and corresponding NUL band should be precluded.***Proposal 3: For inter-band UL CA option 2 with 3 or 4 carriers, supported band combinations can be reported by UE. Study on supported band combinations for R18 Tx switch can be started in RAN 4.*** |
| [9] NOK, NSB | If all these combinations are to be allowed, it can cause a significant ecosystem fragmentation issue. It would be preferrable that a UE indicating support for 3-band or 4-band Tx switching band combination would be required to support 2Tx on all the bands in the combination, as well as any 1Tx band pair of that combination. If this is not the case, the UE capability options can grow uncontrollably as the obvious implication of not requiring the above would be that some 1Tx + 1Tx band pairs would be supported, but some other not, because there is only 1 Tx that can support a set of bands and that Tx can’t simultaneously be allocated to more than 1 band at a time.**Proposal 3:** All the 1Tx+1Tx band pairs within the configured band combination are valid combinations for all Ues supporting the feature |
| [14] SS | For similar reasons the Rel-18 UE capability signaling should also allow the UE to report that only some of the concurrent UL cases for Option 2 are supported for selected 2-bands combinations. Support for dual UL transmissions will be subject to a variety of RF constraints and must be separately considered in RAN4 for the supported band combinations.**Proposal 4:** *Rel-18 UL Tx switching supports UE capability signaling that the UE only supports Option 2 for a subset of 2 bands in a 3- or 4-band combination* |
| [16] MTK | **Supported number on switching cases:** For option#2 of Tx switching where simultaneous transmission on the two bands is supported, the possible case for the 3 bands scenario is provided in the table below. Supporting the switching between all these cases could be challenging for most of the UEs. Also, from network operation perspective, switching between all these cases may not be crucial for the UL performance. Hence, it is essential to allow the UE to report which Tx switching mode (switchedUL or dualUL) is supported for any band combination.1. ***For UL Tx switching among 3/4 bands, the supported Tx switching option (switchedUL or dualUL) is reported per band combination.***
 |
| [17] LG | When the UL Tx switching occurs across 4 bands, those bands can be composed of two different BCs. For example, band A and band B are associated with one BC (BC#1), and band C and band D are associated with another BC (BC#2). At this time, if a UE is configured with the UL Tx switching across those 4 bands (i.e., A, B, C, and D) and the UE reports ‘switchedUL’ for BC#1 and ‘dualUL’ for BC#2, the gNB may need to select which option is to be configured for the UL Tx switching across these 4 bands. Simply, the gNB may configure ‘switchedUL’ to the UE for the UL Tx switching even for BC#2 in conservative way. However, it would be better to configure ‘dualUL’ for the BC#2 to enable simultaneous UL transmissions on band C and band D. In this respect, it may be necessary to discuss how to configure the options for the UL Tx switching across multiple bands belonging to multiple BCs.**Proposal #4: It is necessary to discuss how to configure one of options between {‘switchedUL’, ‘dualUL’} when UL Tx switching is configured for a set of bands belonging to multiple different band combinations.** |
| [18] QC | * To avoid the required resource increased exponentially if both Tx chains are capable of dynamic switch, we think there should be no restriction on the UEs choice of MIMO capability on any of the bands/CCs involved in the Rel-18 UL Tx switching band combination. We prefer Alt. 3 only allow one Tx chain switching flexibly, some cases like Tx at band B+C, C+D would be precluded as it requires both Tx chains on anchor band switches to two different non-anchor bands.

**Proposal 3: For inter-band UL CA Option 1 and Option 2 without SUL, adopt following for UL Tx switching among 3 or 4 bands.*** **Identify an anchor band in the switching band combination. For any RF state switch, either the switch-to or switch-from carrier/band must be the anchor band, and no direct switch between non-anchor bands.**
* **Indirect switch between non-anchor bands is allowed.**
	+ **Indirect switch means that the gap time is increased, which in principle allows going through a two-step RF state switch sequence {non-anchor 🡪 anchor 🡪 other non-anchor}, irrespective of whether transmission in anchor in the middle state is performed or not.**
* **No restriction on the UEs choice of MIMO capability on any of the bands/CCs involved in the Rel-18 UL Tx switching band combination.**
* **After one RF state switch, the next RF state switch must occur after 14 symbols or later.**
	+ **Which SCS assumed for symbol duration is TBD.**

**Proposal 6: For inter-band UL CA Option 1 with SUL, adopt following for UL Tx switching among 3 or 4 bands.*** **Identify an anchor band in the switching band combination among the NUL bands.**
* **For any RF state switch, either the switch-to or switch-from carrier/band must be the anchor band, and no direct switch between non-anchor bands.**
* **Indirect switch between non-anchor bands is allowed.**
	+ **Indirect switch means that the gap time is increased, which in principle allows going through a two-step RF state switch sequence {non-anchor 🡪 anchor 🡪 other non-anchor}, irrespective of whether transmission in anchor in the middle state is performed or not.**
* **No restriction on the UEs choice of MIMO capability on any of the bands/CCs involved in the Rel-18 UL Tx switching band combination**
* **After one RF state switch, the next RF state switch must occur after 14 symbols or later.**

**Which SCS assumed for symbol duration is TBD.** |
| [20] DCM | As shown in the Figure 2 in section 2, the number of supported switching cases is increased especially for Inter-band UL-CA Option 2. However, the Figure 2 is made based on the assumption that any concurrent UL cases (combinations of 2 bands for concurrent UL transmissions) is supported. As captured in the RAN1 observation above, there is a proposal that UE is allowed to report the supports of only some of concurrent UL cases. If this proposal is applied, the number of supported switching cases in Inter-band UL-CA Option 2 is reduced as below.* If the UE supports only X concurrent UL case(s) (X can be from 1 to 3 in case of 3 bands and from 1 to 6 in case of 4 bands), the number of supported switching cases is reduced to 3+X in case of 3 bands and 4+X in case of 4 bands.

This proposal can be realized by introducing a UE capability reporting the supported concurrent UL cases for the UL Tx switching band combination. The details of the capability design should be up to RAN2.**Proposal 2:****For Rel-18 UL Tx switching, allowing flexible support of concurrent UL case(s) for Inter-band CA Option 2 and/or MIMO capability for each band/CC can be considered to reduce the number of supported switching cases and/or supported transmission configurations for complexity reduction.*** **Introduction of UE capability(es) for such flexible support can be discussed in RAN2.**

By the way, as shown in Figure 1 and 2 in section 2, the number of switching cases is large especially in Inter-band UL-CA Option 2 (i.e., dual UL) for 4 bands. Therefore, it may be possible to apply one or multiple of complexity reduction solution(s) only for dual UL case and/or for 4 bands case. With such consideration, we can just apply Alt.1 for 3 bands case and/or switched UL case as straight forward extension from Rel-17 UL Tx switching for 2 bands case, and the performance gain from the extension can be expected. Meanwhile, for dual UL case and/or 4 band case where complexity increase is concerned, we can apply some complexity reduction solution(s) so that complexity increase can be reduced at the cost of slight reduction for performance gain. Anyway, to specify new mechanism, it should be justified by sufficient gain with reasonable/acceptable complexity, otherwise it will not be deployed/implemented in practice. Therefore, we should consider both performance gain and complexity for the good balance.**Proposal 4:****For Rel-18 UL Tx switching, applying some complexity reduction solution(s) only for dual UL case and/or 4 bands case can be considered to achieve the good balance between performance gain and complexity.** |
| [21] E/// | Companies proposed the following during the last meeting:* UE can report the supports of only some of concurrent UL cases (combinations of 2 bands for concurrent UL transmissions)
* Switching across 0/1/2 ports is supported only for 2 configured bands out of 3 or 4 configured bands and other bands support switching across 0/1 port only
* Only switching across 0/1 port is supported across all configured bands when 3 or 4 bands are configured

In our view, the extension of dynamic UL Tx switching to three bands, should ensure additional performance enhancements as compared to legacy procedures that support not only 2 ports transmissions on 2 bands, but also concurrent transmissions on two bands. Consequently, solutions not supporting concurrent transmissions on any of the 2 bands or relying on limiting 2 ports transmission to a single band are not reasonable to be supported.1. Dynamic UL TX switching across 3 or 4 bands for UL CA should include concurrent transmission on any two bands among 3 or 4 bands.
 |

Based on above, the situation can be summarized as below.

### Summary 4.1

|  |
| --- |
| * Support/Supportive for allowing UE supports of only some of concurrent UL cases for Inter-band CA Option 2
	+ [2], [3], [7], [14], [16], [17], [18], [20]
	+ Discuss how to configure one of options for each band pair [17]
	+ Capability design should be up to RAN2 [20]
	+ Support only for 4 bands case [20]
* Not support/supportive, i.e., all band pairs within the configured band combinations should be supported
	+ [9], [21]
	+ At least one band pair should be supported as in Rel-17 [21]
 |

Many companies are supportive for this complexity reduction scheme while there are some companies having concern. The moderator would like to ask companies to provide feedback if any on the above summary and following potential FL proposal.

### **Proposed working assumption 4.1**

* If Rel-18 UL Tx switching is supported, UE is allowed to support only some of concurrent UL cases for Inter-band CA Option 2
	+ FFS: at least one band pair should be supported as in Rel-17
	+ FFS: for both 3 and 4 bands cases or only for 4 bands case
	+ FFS: potential capability/RRC signaling

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| --- | --- |
| Company | Comment |
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## 4.2 Allowing UE supports of 2 ports transmission only on some or none of bands out of configured bands for UL Tx switching

In contributions, following proposals were made for allowing UE supports of 2 ports transmission only on some or none of bands out of configured bands for UL Tx switching.

|  |  |
| --- | --- |
| [2] ZTE | * Limiting the number of bands supporting 2-port. This could be applied for both Alt.1 and Alt.2. For example, for UE indicating support of band combination A+B+C, where band A only supports 1 port transmission and band B/C supports 2 port transmission, in this case, 2T+0T+0T is not supported for Alt.1 and only Rel-16 Tx switching is supported for each band pair A+B and A+C. Limiting the total number of layers among all bands may reduce the implementation cost.

***Proposal 3****: Further discuss the following methods to reduce implementation complexity.** *Limiting the number of bands supporting 2-port.*
* *Limiting the number of supported band pairs.*
* *Limiting one anchor band as Alt.3.*
* *Allowing HW resources (e.g., cache) switching between band pairs together with UL Tx switching.*
 |
| [3] SPRD | For switching across **0/1/2 ports is supported only for 2 configured bands** out of 3 or 4 configured bands and other bands support switching across 0/1 port only, it needs some clarifications to have a common understanding towards two ports switching. In our understanding, 0 port switching is no UL Tx switching, the previous state is as same as the current state or they are within the same Tx chains case. 1 port and 2 ports switching require UL Tx switching. For example, from 0P+0P+1P in case 3 to 0P+1P+0P in case 1 is 1 port switching. Since there is up to 1 port transmission in the previous state and the current state. Similarly, when there are up to 2 ports switching among the switching states, they are 2 ports switching, such as from 0P+0P+2P in case 5 to 0P+1P+0P in case 4. Based on those understanding, 2 ports switching requires more Tx chains operation at one time, i.e. when switching from 0P+0P+2P in case 5 to 0P+1P+0P in case 4, UE needs to switch the two Tx chain from one case to another switching cast at the same time. Clearly, some bands combinations can be support, while some bands cannot be easy to support this comparatively complex operation. Therefore, we support this method.For **only switching across 0/1 port is supported across all configured bands** when 3 or 4 bands are configured, it can be supported. For example, when uplink Tx switching cross 3 bands, it can be scheduled to switch from 1P+1P+0P in case 1 to 0P+0P+1P in case 2 or case 3 or case 5, all three bands are involved, then up to 1 port can be applied. But 1P+1P+0P in case 1 to 0P+0P+2P in case 5 cannot be scheduled, because there are 2 ports switching under this condition. 1. ***At least the following can be studied further for Rel-18 UL Tx switching together with Alt1.***
* ***UE can report the supports of only some of concurrent UL cases (combinations of 2 bands for concurrent UL transmissions)***
* ***Switching across 0/1/2 ports is supported only for 2 configured bands out of 3 or 4 configured bands and other bands support switching across 0/1 port only***
* ***Only switching across 0/1 port is supported across all configured bands when 3 or 4 bands are configured***
1. ***UE capability can be used together with the above complexity reduction methods.***
 |
| [9] NOK, NSB | If all these combinations are to be allowed, it can cause a significant ecosystem fragmentation issue. It would be preferrable that a UE indicating support for 3-band or 4-band Tx switching band combination would be required to support 2Tx on all the bands in the combination, as well as any 1Tx band pair of that combination. If this is not the case, the UE capability options can grow uncontrollably as the obvious implication of not requiring the above would be that some 1Tx + 1Tx band pairs would be supported, but some other not, because there is only 1 Tx that can support a set of bands and that Tx can’t simultaneously be allocated to more than 1 band at a time.**Proposal 2:** The UE indicating support for UL Tx switching for 3-band or 4-band band combination should be able to transmit 2Tx on all the 3 or 4 bands |
| [13] CT | For inter-band UL CA Option 1 with and without SUL, if there is a band supporting only 1Tx chain, 2 antenna ports for UL transmission on that band is not supported. For example, if only 1Tx chain is supported for Band A, case 1 in proposal 3 needs to be modified to 1T+0T+0T/1P+0P+0P, case 1 in proposal 4 needs to be modified to 1T+0T+0T+0T /1P+0P+0P+0P.**Observation 1: For Rel-18 UL Tx switching, if one or multiple of the 3 or 4 bands support(s) only 1Tx chain, 1Tx on a band maps to 1 antenna port UL transmission on that band as the mapping between Tx chains and UL transmission antenna ports for inter-band UL CA Option 1 with and without SUL.**For inter-band UL CA Option 2 without SUL, the mapping cases in proposal 6,7 are listed considering each band can support maximum 2Tx chain. If there is a band supporting only 1Tx chain, the case with 2T on that band is removed. For example, if only 1Tx chain is supported for Band A, cases 1 in proposal 6,7 need to be removed.**Observation 2: For Rel-18 UL Tx switching, if one or multiple of the 3 or 4 bands support(s) only 1Tx chain, there is no case with 2Tx on a band supporting only 1Tx chain mapping to 2 or 1 antenna port UL transmission on that band for inter-band UL CA Option 2 without SUL.**As is observed from observation 1 and 2, if one or multiple of the 3 or 4 bands support(s) only 1Tx chain, the mapping cases between Tx chains and UL transmission antenna ports are reduced. The switching cases are subset of the switching cases when all the 3 or 4 bands support up to 2Tx. Since 1Tx-2Tx, 2Tx-2Tx UL Tx switching is reported by UE capability and configured by gNB in the previous release, the switching configurations with at least 1 band out of 3 or 4 bands supporting up to 2Tx are also based on UE capability and gNB configuration in Rel-18.**Proposal 10: For Rel-18 UL Tx switching, at least 1 band out of 3 or 4 bands supports up to 2Tx.** |
| [14] SS | Figures 1 and 2 show two examples for possible FR1 antenna and RF path mappings in the UE when configured for 3 or 4 NR bands. Figure 1 is the case of a 3-band 700MHz (SUL) + 2.6GHz (TDD NUL) + 3.5GHz (TDD NUL) configuration, e.g., across LB and higher MB. Figure 2 shows the case of a 4-band 2.3GHz (SUL) + 2.6GHz (TDD NUL) + 3.5GHz (TDD NUL) + 4.9 GHz (TDD NUL) configuration, e.g., across lower and higher MB. For simplicity, only the UE UL Tx-side mapping is shown. Due to practical UE implementation constraints, we expect that UL Tx switching many cases will only support UL Tx switching for 1p/0p combinations on the NR band. A few NR bands, e.g., such as some benign lower/higher MB NR band combinations not suffering from IMD3/5 may reasonably well be expected to support UL MIMO with possible 2p/1p/0p configurations. However, it should not be assumed that even when UL Tx switching on an UL MIMO band is supported by the UE that 2p is then always possible across all the configured NR bands. In the example of Figure 1, UL MIMO is supported for TDD NUL 3.5 GHz using antenna paths p2 & p2bis, but TDD NUL 2.6 GHz can only use the p2 path, e.g., 1p or 0p.Therefore, we consider that 3-band or 4-band switching cases 1p/0p are of most immediate relevance when considering likely commercial UE implementations. In addition, some NR bands, e.g., mid-band TDD may support UL MIMO for some bands and support for switching cases 2p/1p/0p may be needed (if the UE implementation supports 2p switching).**Observation 1:** *Full flexible port switching, e.g., any UE Tx chain can be mapped to any arbitrary band configurable for 3- or 4-bands UL Tx Switching is not a realistic assumption.***Observation 2:** *Support for full flexible 2p/1p/0p port switching in the NR band where UL MIMO is supported by the UE cannot be assumed.*In summary, we consider that the approach to be taken for Rel-18 UL Tx switching in the 3- or 4-bands case is to assume 1 available fixed Tx chain per NR band where Rel-18 UL Tx switching is supported by the UE. Note that this approach is similar to Rel-16 UL Tx switching for the 2-bands case. Then, selective switching of another Tx chain for purpose of either 2p/1p/0p or 1p/0p switching from another NR band should be allowed by core specifications. The Rel-18 UE should indicate its 2p/1p/0p switching capability separately for those NR bands where such a feature is supported and then only for the configured band (and band combinations). Default Rel-18 UE port switching capability for 3- or 4-bands cases is then the support of switching for 1p/0p. Full flexible switching across 0/1/2 ports is then only supported for at most 2 configured bands out of 3 or 4 configured bands while the other bands then support switching across 0/1 ports only.***Proposal 1:*** *(3-bands) switching configuration 3-2: only 1 band out of 3 bands support up to 2Tx****Proposal 2:*** *(4-bands) switching configuration 4-2: only 1 band out of 4 bands support up to 2Tx*To make the Rel-18 UL Tx Switching feature with 2 Tx chains for the 3- or 4-bands cases viable, it is necessary to allow for different UE & modem vendor implementation paths. If it is required to implement full flexible 2p/1p/0p port switching for any carrier in any NR band with UL MIMO support for which the UE also indicates support for Rel-18 3 UL Tx switching using 3- or 4-bands, such a feature is not likely to be implemented. If the UE implementation provides support for UL MIMO in an NR band, such support should be separately indicated by the UE through the corresponding UE capability signaling for the supported NR band (and band combination). It should not be necessary to link UL MIMO for the NR band with use of that band for UL Tx switching, e.g., require support for 2p switching capability when UL MIMO is supported in the NR band by the UE.**Proposal 3:** *Rel-18 UL Tx switching for 3- or 4-bands should not result in restriction on the Ues choice of MIMO capability on any of the bands / CCs involved in the UL Tx* |
| [15] CMCC | It is commented that the switching configuration should be considered due to the potential complexity when fully dynamic Tx switching across 3 or 4 bands is enabled. According to the motivation of the WI on multi-carrier enhancement, it is important to ensure the available scattered spectrum bands or wider bandwidth spectrum can be utilized in a more spectral/power efficient and flexible manner, which may potentially lead to higher UL data rate, spectrum utilization and UL capacity. From our perspective, to make full use of the scattered spectrum bands, there is no need to limit only 1Tx transmission on one or more certain bands in the specification, which can just depend on UE and gNB implementation.**Proposal 2. For any switching mechanism, both of two Tx chains can switch to any of 3 or 4 bands to provide scheduling flexibility and performance improvements.** |
| [18] QC | * To avoid the required resource increased exponentially if both Tx chains are capable of dynamic switch, we think there should be no restriction on the UEs choice of MIMO capability on any of the bands/CCs involved in the Rel-18 UL Tx switching band combination. We prefer Alt. 3 only allow one Tx chain switching flexibly, some cases like Tx at band B+C, C+D would be precluded as it requires both Tx chains on anchor band switches to two different non-anchor bands.

**Proposal 3: For inter-band UL CA Option 1 and Option 2 without SUL, adopt following for UL Tx switching among 3 or 4 bands.*** **Identify an anchor band in the switching band combination. For any RF state switch, either the switch-to or switch-from carrier/band must be the anchor band, and no direct switch between non-anchor bands.**
* **Indirect switch between non-anchor bands is allowed.**
	+ **Indirect switch means that the gap time is increased, which in principle allows going through a two-step RF state switch sequence {non-anchor 🡪 anchor 🡪 other non-anchor}, irrespective of whether transmission in anchor in the middle state is performed or not.**
* **No restriction on the UEs choice of MIMO capability on any of the bands/CCs involved in the Rel-18 UL Tx switching band combination.**
* **After one RF state switch, the next RF state switch must occur after 14 symbols or later.**
	+ **Which SCS assumed for symbol duration is TBD.**

**Proposal 6: For inter-band UL CA Option 1 with SUL, adopt following for UL Tx switching among 3 or 4 bands.*** **Identify an anchor band in the switching band combination among the NUL bands.**
* **For any RF state switch, either the switch-to or switch-from carrier/band must be the anchor band, and no direct switch between non-anchor bands.**
* **Indirect switch between non-anchor bands is allowed.**
	+ **Indirect switch means that the gap time is increased, which in principle allows going through a two-step RF state switch sequence {non-anchor 🡪 anchor 🡪 other non-anchor}, irrespective of whether transmission in anchor in the middle state is performed or not.**
* **No restriction on the UEs choice of MIMO capability on any of the bands/CCs involved in the Rel-18 UL Tx switching band combination**
* **After one RF state switch, the next RF state switch must occur after 14 symbols or later.**

**Which SCS assumed for symbol duration is TBD.** |
| [20] DCM | In addition, as captured in the RAN1 observation above, there are some proposals for flexible support of the MIMO capability (i.e., maximum number of ports) for each band/CC in UL Tx switching band combination. If such proposal is applied, the number of supported transmission configurations based on number of antenna ports in each band for actual transmission can be reduced as below.* If the UE supports up to 2 ports transmission on any band in case of Inter-band UL-CA Option 1 for 3 or 4 bands, the number of supported transmission configurations is 6 or 8 for 3 or 4 bands, respectively (1 port on band A, 2 ports on band A, 1 port on band B, 2 ports on band B, and so on).
* If the UE supports up to 2 ports transmission only on X band(s) in case of Inter-band UL-CA Option 1 for 3 or 4 bands (X can be from 0 to 3 in case of 3 bands and from 0 to 4 in case of 4 bands), the number of supported transmission configurations is 3+X for 3 bands and 4+X for 4 bands, respectively.

This proposal can also be handled by UE capability reporting the MIMO capability on each band/CC for the UL Tx switching band combination. The details of the capability design should be up to RAN2 as well.**Proposal 2:****For Rel-18 UL Tx switching, allowing flexible support of concurrent UL case(s) for Inter-band CA Option 2 and/or MIMO capability for each band/CC can be considered to reduce the number of supported switching cases and/or supported transmission configurations for complexity reduction.*** **Introduction of UE capability(es) for such flexible support can be discussed in RAN2.**

By the way, as shown in Figure 1 and 2 in section 2, the number of switching cases is large especially in Inter-band UL-CA Option 2 (i.e., dual UL) for 4 bands. Therefore, it may be possible to apply one or multiple of complexity reduction solution(s) only for dual UL case and/or for 4 bands case. With such consideration, we can just apply Alt.1 for 3 bands case and/or switched UL case as straight forward extension from Rel-17 UL Tx switching for 2 bands case, and the performance gain from the extension can be expected. Meanwhile, for dual UL case and/or 4 band case where complexity increase is concerned, we can apply some complexity reduction solution(s) so that complexity increase can be reduced at the cost of slight reduction for performance gain. Anyway, to specify new mechanism, it should be justified by sufficient gain with reasonable/acceptable complexity, otherwise it will not be deployed/implemented in practice. Therefore, we should consider both performance gain and complexity for the good balance.**Proposal 4:****For Rel-18 UL Tx switching, applying some complexity reduction solution(s) only for dual UL case and/or 4 bands case can be considered to achieve the good balance between performance gain and complexity.** |
| [21] E/// | Companies proposed the following during the last meeting:* UE can report the supports of only some of concurrent UL cases (combinations of 2 bands for concurrent UL transmissions)
* Switching across 0/1/2 ports is supported only for 2 configured bands out of 3 or 4 configured bands and other bands support switching across 0/1 port only
* Only switching across 0/1 port is supported across all configured bands when 3 or 4 bands are configured

In our view, the extension of dynamic UL Tx switching to three bands, should ensure additional performance enhancements as compared to legacy procedures that support not only 2 ports transmissions on 2 bands, but also concurrent transmissions on two bands. Consequently, solutions not supporting concurrent transmissions on any of the 2 bands or relying on limiting 2 ports transmission to a single band are not reasonable to be supported.**Dynamic UL TX switching across 3 or 4 bands should include 2 TX transmission (i.e. 0/1/2 ports transmission) on any of the 3 or 4 bands.** |

Based on above, the situation can be summarized as below.

### Summary 4.2

|  |
| --- |
| * Support/Supportive for allowing UE supports of 2 ports transmission only on some or none of bands out of configured bands for UL Tx switching
	+ [2], [3], [13], [14], [18], [20]
	+ At least 1 band out of 3 or 4 bands should support up to 2 Tx [13]
	+ Only 1 band out of 3 or 4 bands should support up to 2 Tx [14, 18]
	+ Capability design should be up to RAN2 [20]
	+ Support only for 4 bands case and/or Option 2 case [20]
* Not support/supportive, i.e., both of two Tx chains should be able to switch to any of 3 or 4 bands
	+ [9], [15], [21]
	+ At least two bands should support up to 2 Tx as in Rel-17 [21]
 |

Multiple companies are supportive for this complexity reduction scheme while there are some companies having concern. The moderator would like to ask companies to provide feedback if any on the above summary and following potential FL proposal.

### **Proposed working assumption 4.2**

* If Rel-18 UL Tx switching is supported, UE is allowed to support 2 ports transmission only on some of bands out of configured bands for UL Tx switching
	+ FFS: at least two bands should support up to 2 Tx as in Rel-17
	+ FFS: for both 3 and 4 bands cases or only for 4 bands case
	+ FFS: for both Option 1 and 2 cases or only for Option 2 case
	+ FFS: potential capability/RRC signaling

|  |  |
| --- | --- |
| Company | Comment |
|  |  |
|  |  |
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## 4.3 Allowing UE to have more preparation procedure time for specific switching cases/patterns

In contributions, following proposals were made for allowing UE to have more preparation procedure time for specific switching cases/patterns.

|  |  |
| --- | --- |
| [1] HW, HiSi | Before the start of an UL transmission on a switch-to band, all information for the band should be prepared and ready in the UE memory. For example, as illustrated in Figure 5, when the 3rd UL Tx switching from band B to band C is triggered via DCI, since essential baseband and RF information for UL transmissions on band C is not pre-stored in the memory, the UE needs to flush the memory of band A and then reload it with the new information for band C before the UE can use this information to transmit data on band C starting at the 3rd UL Tx switching. Therefore, compared with Rel-17, from the UE perspective, more UE preparation are needed before transmitting data on the switch-to band. In another word, more preparation procedure time is required, e.g., 500us. Furthermore, the specific additional preparation procedure time can be reported by UE depending on the UE capabilities. It can be also found that flushing memory of band A and loading band C do not start immediately at the time of receiving DCI of 3rd UL Tx switching in Figure 5. The reason is that the memory is still occupied for the transmission on band A and any transmission interruption of band A caused by memory sharing should be avoided. Therefore, the memory flushing action to prepare a transmission should not overlap in time with any other previous transmission that share the same UE memory with it.It is worth noting that, the flushing and reloading action is not always needed for all UL Tx switching occasions. For example, as illustrated in Figure 5, when the 2nd UL Tx switching from band A to band B is triggered, since the information on band B has been pre-stored in the memory, the flushing and reloading action is not needed. Therefore, it does not require additional UE action before transmitting data on the switch-to band, and current preparation procedure time is sufficient.**Figure 5** The case that 2 units of memory are shared among three bands.***Proposal 2:*** *For dynamic UL Tx switching across 3 or 4 bands, to support a sharing of UE memory across bands,* * *When memory is flushed and reloaded, more preparation procedure time is needed for both Option 1 and Option 2, whose increased time can be reported by UE. FFS: exact time value.*
* *The memory flushing required by the preparation of a transmission scheduled by a latest UL grant should not impact any ongoing UE transmission on any bands that are scheduled before the UL grant. FFS: the minimum gap between the transmission scheduled by a UL grant and the previous transmission that may share the same UE memory.*
 |
| [20] DCM | Alt.2 is one way to relax the timeline for “dynamic switching” by requiring DCI or MAC-CE indication compared with Alt.1/3 where the dynamic switching is based only on the UL scheduling. For example, in Alt.2, a certain timeline for the reconfiguration of the candidate bands for dynamic switching based on UL scheduling would need to be defined so that UE can process and complete the reconfiguration before performing UL Tx switching to the band currently not configured for Tx chains as shown in Figure 3.However, such relaxation of the timeline for dynamic switching would be possible in Alt.1 as well, i.e., even without using DCI or MAC-CE indication. For example, as shown in Figure 4, when UL is scheduled for the band (which is different from the recently used bands) with sufficient scheduling offset, the UE can perform same/similar reconfiguration of candidate bands for dynamic switching as in Alt.2. Compared with Alt.2 where new DCI or MAC-CE indication needs to be processed, Alt.1 with scheduling offset based on a certain timeline would be better in terms of specification impacts and overhead due to new DCI or MAC-CE indication.**Proposal 3:****For Rel-18 UL Tx switching, defining a certain timeline for dynamic switching to specific case(s) can be considered to relax the timeline for dynamic switching in some specific case(s) for complexity reduction.**By the way, as shown in Figure 1 and 2 in section 2, the number of switching cases is large especially in Inter-band UL-CA Option 2 (i.e., dual UL) for 4 bands. Therefore, it may be possible to apply one or multiple of complexity reduction solution(s) only for dual UL case and/or for 4 bands case. With such consideration, we can just apply Alt.1 for 3 bands case and/or switched UL case as straight forward extension from Rel-17 UL Tx switching for 2 bands case, and the performance gain from the extension can be expected. Meanwhile, for dual UL case and/or 4 band case where complexity increase is concerned, we can apply some complexity reduction solution(s) so that complexity increase can be reduced at the cost of slight reduction for performance gain. Anyway, to specify new mechanism, it should be justified by sufficient gain with reasonable/acceptable complexity, otherwise it will not be deployed/implemented in practice. Therefore, we should consider both performance gain and complexity for the good balance.**Proposal 4:****For Rel-18 UL Tx switching, applying some complexity reduction solution(s) only for dual UL case and/or 4 bands case can be considered to achieve the good balance between performance gain and complexity.** |
| [21] E/// | Companies proposed the following as well:* After one RF state switch, the next RF state switch must occur after 14 symbols or later (FFS: which SCS is assumed for the symbol duration)

The above proposal was motivated by the proponents due the additional complexity that extension of dynamic UL Tx switching operation to more bands imposes to a UE. The complexity is claimed to stem from the need for additional memory, and related operations such as flushing or data transfer. However, the proposal does not distinguish between legacy Tx chain state transitions and the new ones under discussion in Rel-18. Without any distinction scheduling delay would be unnecessarily increased. Consider for example that the UE supports dynamic UL Tx switching across 3 bands and consequently the NW configures the UE to enable dynamic TX switching across 3 bands. However, for set of transmissions that are confined within 2 of the 3 bands, additional delay would be imposed as compared to the legacy case which is not reasonable. The additional delay should only be effective, if needed, when the 3rd band is involved in the corresponding procedures. That means that the performance should not be reduced for transmission across 2 of the 3 or 4 bands, as compared to the legacy procedures.In our view, to support Alt 1 while addressing the claimed UE complexity, the notion of anchor band to switch a TX chain to/from, can be reflected properly in the procedure such that the relaxed UE complexity does not result in scheduling complexity. 1. Apply the following procedures for dynamic UL Tx switching across 3 or 4 bands:
	* 1. Indicate N band(s) among 3 or 4 bands are configured as anchor band(s).
			1. N = 1 for dynamic UL TX switching across 3 bands
			2. N = 2 for dynamic UL TX switching across 4 bands (FFS N=1)
		2. For an indicated UL transmission, if after the preceding UL transmission, the UE is under operation state that is different from the ending state, and if none of the bands in the ending and operation states are an anchor band, the UE expects that the indicated UL transmission to occur after at least a gap of duration X after the end of the proceeding transmission.
			1. Note: *Operation state* refers to the state of Tx chains on two bands before an indicated UL transmission
			2. Note: *Ending state* refers to the state of Tx chains on two bands after transmission of an indicated UL transmission
			3. FSS on X (e.g. slot duration corresponding to the band w largest SCS)
 |

Based on above, the situation can be summarized as below.

### Summary 4.3

|  |
| --- |
| * Support/Supportive for allowing UE to have more preparation procedure time for specific switching cases/patterns
	+ [1], [20], [21]
	+ longer preparation time is applied when memory flushing/reloading is required [1]
	+ required preparation time is reported by UE [1]
	+ longer preparation time is applied when scheduled band is different from the recently used bands [20]
	+ longer preparation time is applied when switching involves non-anchor band(s) [21]
 |

The moderator would like to ask companies to provide feedback if any on the above summary and companies proposals.

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| --- | --- |
| Company | Comment |
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## 4.4 Allowing UE supports of limited switching cases/patterns

In contributions, following proposals were made for allowing UE supports of limited switching cases.

|  |  |
| --- | --- |
| [2] ZTE | * Limiting the switching cases. This could be directly applied for Alt.1, and can be also applied for Alt.2 with DCI indicating band pair. Based on our understanding, this may not reduce the implementation complexity since in the end UE has to support UL Tx switching among all the bands. Meanwhile, this will greatly impact the network scheduling since network has to ensure some potential scheduling sequence is not allowed.

Based on the above analysis, limiting the switching cases is not a proper way to reduce implementation. |
| [6] FJT | * UE capability is introduced to report the available combinations of anchor and non-anchor band at a UE
	+ *Justification: UE is not required to implement all the band combination for UL Tx switching.*
* Anchor and non-anchor relationship among CCs is configured by gNB based on the UE capability, and the actual UL Tx switching can be performed among the CCs.
	+ FFS: the details of anchor/non-anchor relationship
	+ *Justification:*
		- *UE is not required to keep the UL Tx information for each CC by limiting the switching cases*

**Proposal 1:*** *If dynamic Tx carrier switching scheme is specified, adopt Alt-3 with the following understanding:*
	+ *UE capability is introduced to report the available combinations of anchor and non-anchor band for a UE*
	+ *Anchor and non-anchor relationship among CCs is configured by gNB*
		- *FFS: the details of anchor/non-anchor relationship*
	+ *Actual UL carrier switching is performed by UL grant and/or RRC configuration for UL transmission*
		- *Carriers with anchor and non-anchor relationship cannot be scheduled simultaneously, i.e. gNB scheduler shall avoid such situations.*
 |
| [8] CATT | * Scheme 1: all UL Tx switching cases are supported in R18 specification, and the supported UL TX switching cases of UE are configured by RRC signaling according to the UE capability.
	+ In this scheme, R18 specification supports all UL Tx switching cases. For example, when 4 bands are configured with inter-band UL CA option 2, the UE can be scheduled or configured a ‘2-port UL transmission’ on any one band or two ‘1-port UL transmission’ simultaneously on any two bands among 4 band. There are total 10 cases as described in above section.
	+ From UE perspective, the capability of supported UL TX switching should be reported. According to the reported UE capability, the gNB can configured UL TX switching cases to UE.
* Scheme 2: A sub-set UL Tx switching cases are supported in R18 specification.

In this scheme, some of UL Tx switching cases will be selected to be supported in R18. Only UL TX switching mechanism for the sub-set of all UL TX switching cases are required to specify. One example of candidates cases as following * Only 1 band out of 4 bands support up to 2Tx
* Only switching across 0/1 port is supported across all 4 configured bands

The shortage of scheme 2 is that restriction on switching cases will reduce scheduling flexible, and there is no obvious benefit to reduce specification work load. For example when “only 1 band out of 4 bands support up to 2Tx”, though the switching case can be reduced to 7, but there are still 3 new switching cases that need switching period.**Proposal 10: All UL Tx switching cases are supported in R18 specification, and gNB can configure sub-set of switching cases according to reported UE capability.** |
| [9] NOK, NSB | Furthermore it is important to agree that all transitions between valid Tx switching combinations are supported so that the “before switch” configuration does not limit which “after switch” configurations are allowed.**Proposal 4:** Switching directly from any valid transmit combination to any other valid transmit combination issupported by all the Ues supporting the feature |
| [14] SS | We consider that dynamic UL scheduling via UL grant across at least 3 configured bands is necessary to benefit from potential gains using the Rel-18 UL Tx Switching feature. If RRC re-configuration is required to re-configure 2 bands out of the 3 or 4 supported bands, dynamic UL switching cannot be fully exploited using either Alt. 2 or Alt.3. On the other hand, for those UEs indicating Rel-18 support for 2p/1p/0p switching on some bands, RRC configuration of allowable subsets of possible switching configurations for use with the existing UL grant format becomes necessary. Therefore, modified Alt.2 where the network configures the switching cases for such UE is meaningful. Note that such an approach is slightly different when compared to RAN1#109-e Alt.2 where the gNB indicates 2 bands out of the configured bands (3 or 4 bands) via DCI or MAC-CE. Accordingly, no prioritization rules between UL carriers are necessary.**Proposal 6:** *Rel-18 UL Tx switching supports modified Alt.2: gNB configures the set of port switching cases which can be indicated by DCI for dynamic UL scheduling by RRC* |

Based on above, the situation can be summarized as below.

### Summary 4.4

|  |
| --- |
| * Support/Supportive for allowing UE to support limited switching cases/patterns
	+ [6], [8], [14]
	+ Anchor and non-anchor relationship among CCs is configured by gNB based on UE capability: [6]
	+ gNB can configure sub-set of switching cases according to reported UE capability [8, 14]
* Not support/supportive, i.e., all switching cases/patterns should be supported
	+ [2], [9]
 |

The moderator would like to ask companies to provide feedback if any on the above summary and companies proposals.

|  |  |
| --- | --- |
| Company | Comment |
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## 4.5 Defining/indicating prioritization rules between uplink carriers

In contributions, following proposals were made for defining prioritization rules between uplink carriers.

|  |  |
| --- | --- |
| [3] SPRD | For **prioritization rules between uplink carriers**, we are open to take it into account. But it should be limited into some specific switching cases, and give the specific prioritization rule accordingly, to guarantee the same understanding of Tx chain states between gNB and UE. It should be used based on UE capability report, only if UE report support one switching case with prioritization rule. Thus, the prioritization rules should be careful studied before adopt this solution. |
| [5] Sony | To achieve a dynamic behavior with as little overhead as possible a band prioritization rule could potentially be shared by the gNB in a higher layer rather than dynamic indications. This would enable the UE to autonomously perform the switching, while maintaining the predictability in its switching. **Observation 2: To achieve high dynamic behavior with little overhead, band switching rules can be shared with the UE for autonomous switching.** Potentially a set of different rules can be defined whereas the gNB refer to one of them when it configures the UE. This will also enable the UE to use optimal UE antenna configurations as gives predictability over what band combinations that will be used.**Proposal 1: We propose to go ahead with Alt 1, with a higher layer switching rule indication to enable the UE to do autonomous switching among 3 or 4 carriers.**  |
| [12] IDC | The scheduler can use the following mechanisms to dynamically allocate UL resources in different UL bands while avoiding exceeding UE capability:* DCI-based scheduling such as dynamic grants (for PUSCH) or assignments (for PUCCH) or CG type 2.
* SCell activation/deactivation
* UL BWP dynamic switching

DCI-based scheduling obviously brings a lot of flexibility due to possibility of triggering transmission on-demand. However, scheduling every single UL transmission only with DCI may not be efficient from PDCCH overhead perspective, especially when traffic follows a periodic pattern or for periodic link adaptation purpose. For such purposes, semi-statically configured resources such as configured grants or periodic SRS are better suited. However, once such resources are configured in certain occasions for an UL carrier, the scheduler loses flexibility to utilize other UL carriers in these occasions even if they may be better suited considering propagation and load conditions. The network can also use SCell activation/deactivation to control which UL carrier(s) the UE utilizes without relying only on DCI-based scheduling. However, this prevents scheduling on corresponding DL carrier(s), and may lead to interruptions and activations delay. The network could also configure two (or more) UL BWP’s for each carrier, where one of the UL BWP’s does not comprise any semi-statically configured resource. Using DCI-based BWP switching the network can turn on and off transmission on each carrier with lower latency than SCell activation/deactivation. However, this requires the UE to support dynamic BWP switching feature and would consume an UL BWP for the only purpose of removing UL resources on the carrier.***Observation: Scheduling flexibility may be restricted if UL Tx switching is only supported by using existing signaling*****Defining an active subset of UL carriers**The above limitations could be overcome by specifying a mechanism allowing the network to directly control the subset of UL carriers over which the UE transmits, i.e. a “prioritized” (or active) set of UL carriers. For UL carriers outside of this subset, the UE does not transmit on the semi-statically configured resources (e.g. configured grants or SRS) and does not expect to receive dynamic signaling scheduling a transmission. The network can then indicate and/or update the prioritized subset of UL carriers using MAC CE or DCI while ensuring that the UE capability is not exceeded (including required switching times).***Proposal 1: UE only transmits on UL carriers that belong to a prioritized subset of configured UL carriers.******Proposal 2: MAC or DCI signaling can update the prioritized subset of UL carriers.***For the indication or update of the prioritized subset of configured UL carriers, several options can be envisioned, e.g.:1. MAC CE explicitly indicating the prioritized subset;
2. DCI explicitly indicating the prioritized subset (signaling could be analogous to dormant DL BWP);
3. Prioritized subset includes UL carrier(s) indicated by latest received DCI.

These options could be further investigated in a next step. One may also consider that the UL carrier of the PCell is always in the prioritized subset. |
| [14] SS | **Proposal 7:** *No UL prioritization rules between UL carriers are specified*  |
| [17] LG | When simultaneous UL transmissions occur on three bands (e.g., one scheduled UL on band A, another scheduled UL on band B and other UL configured by RRC on band C), if one or two of UL transmissions on specific band(s) has higher priority than others, the UL Tx switching can be occurred. As an example, for the case where one Tx chain is on band A and another Tx chain is on band B, when two 1-port PUSCH transmissions are scheduled on band A and band C while periodic SRS is configured on band B, the UL Tx switching can be occurred in band B and band C since PUSCH on band C has higher priority than P-SRS on band B. However, as an opposite case, if the UL transmission on band B has higher priority than the UL on band C, the UL Tx switching may not be occurred. **Proposal #5: It can be considered to apply additional UL Tx switching conditions in case when simultaneous UL transmissions occur on more than 2 bands (e.g. based on the priority of the transmitted UL channels).** |
| [20] DCM | For the first proposal regarding prioritization rules, although it may be able to reduce the gNB complexity for performing appropriate scheduling considering 3 or 4 bands with UE’s capabilities on UL Tx switching, it would increase UE complexity since UE needs to check and follow the prioritization rules in some cases where UE cannot just follow gNB scheduling. Considering that the major concern for Rel-18 UL Tx switching would be the complexity increase at UE side, it would not be preferable solution.  |
| [21] E/// | Companies proposed the following during the last meeting* Prioritization rules between uplink carriers are specified

Similar to the previous discussion, any prioritization rule, limits the scheduler and consequently makes the usefulness of the feature questionable. If addition of a new band to the operation causes additional complexity, the complexity should be addressed without compromising the operation through adding new rules, or conditions for transmissions on any of these bands.  |

Based on above, the situation can be summarized as below.

### Summary 4.5

|  |
| --- |
| * Support/Supportive for defining and/or indicating prioritization rules between uplink carriers
	+ [5], [12], [17]
	+ Higher layer switching rule indication: [6]
	+ MAC or DCI signaling to update the prioritized subset of UL carriers: [12]
* Not support/supportive
	+ [3], [14], [20], [21]
 |

The moderator would like to ask companies to provide feedback if any on the above summary and companies proposals.

|  |  |
| --- | --- |
| Company | Comment |
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## 4.6 Defining minimum switching interval

In contributions, following proposals were made for defining minimum switching interval.

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| --- | --- |
| [11] Xiaomi | Considering more than two UL bands can be supported for UL Tx switching, e.g. 4 UL bands, if the minimum granularity of UL Tx switching is still determined by the two UL bands on which switching happens, it may be impossible for UL switching on other band pair. One example is shown in Figure 6, assuming there are 4 UL bands are configured for UL Tx switching, i.e. {band#1, band#2, band#3, band#4}. The SCS is {30kHz, 15kHz, 15kHz, 15kHz} respectively. Assuming switching granularity is determined only by two UL bands on which UL Tx switching is happening, the following results can be observed:* UL Tx switching from band#2 to band#3 becomes impossible. UE only expects one uplink switching in a slot with *µUL* = max(*µband#2, µband#3*)=15kHz. However, there is already one switching within the slot, i.e. uplink switching from band#1 to band#2. It brings additional restriction for UL Tx switching and results in more delay.

In order to address the above issue, the switching granularity can be determined by the largest SCS among four UL bands for UL Tx switching.***Proposal 3: The UE does not expect to perform more than one uplink switching in a slot with µUL, wherein µUL is the largest SCS among all bands configured for UL Tx switching.*** |
| [18] QC | * Meanwhile, as the switching bands increase, the UE needs to monitor more switching decisions we propose to avoid frequent scheduling within 14 consecutive symbols.

**Proposal 3: For inter-band UL CA Option 1 and Option 2 without SUL, adopt following for UL Tx switching among 3 or 4 bands.*** **Identify an anchor band in the switching band combination. For any RF state switch, either the switch-to or switch-from carrier/band must be the anchor band, and no direct switch between non-anchor bands.**
* **Indirect switch between non-anchor bands is allowed.**
	+ **Indirect switch means that the gap time is increased, which in principle allows going through a two-step RF state switch sequence {non-anchor 🡪 anchor 🡪 other non-anchor}, irrespective of whether transmission in anchor in the middle state is performed or not.**
* **No restriction on the UEs choice of MIMO capability on any of the bands/CCs involved in the Rel-18 UL Tx switching band combination.**
* **After one RF state switch, the next RF state switch must occur after 14 symbols or later.**
	+ **Which SCS assumed for symbol duration is TBD.**

**Proposal 6: For inter-band UL CA Option 1 with SUL, adopt following for UL Tx switching among 3 or 4 bands.*** **Identify an anchor band in the switching band combination among the NUL bands.**
* **For any RF state switch, either the switch-to or switch-from carrier/band must be the anchor band, and no direct switch between non-anchor bands.**
* **Indirect switch between non-anchor bands is allowed.**
	+ **Indirect switch means that the gap time is increased, which in principle allows going through a two-step RF state switch sequence {non-anchor 🡪 anchor 🡪 other non-anchor}, irrespective of whether transmission in anchor in the middle state is performed or not.**
* **No restriction on the UEs choice of MIMO capability on any of the bands/CCs involved in the Rel-18 UL Tx switching band combination**
* **After one RF state switch, the next RF state switch must occur after 14 symbols or later.**

**Which SCS assumed for symbol duration is TBD.** |
| [19] Apple | In our view, if Alt 2 is adopted, most of the concerns related to UE/gNB complexity increase can be alleviated. However, further restrictions can be considered depending on flexibility requirements, UE capability, etc. One possibility to consider with Alt 2 is support additional restriction in terms of minimum duration between two consecutive instances of indicating a pair of bands from the configured 3 or 4 bands. MAC CE based indication of a band pair will at least ensure a gap of 3ms between two consecutive instances, however, further additional configurable values can be supported. This would help to avoid very frequent updates of pair for UL Tx switching.***Proposal 5: RAN1 should consider further restriction in terms of minimum required duration between two consecutive updates of band pair for Alt 2 based UL Tx switching mechanism***  |
| [20] DCM | For the second proposal regarding minimum switching gap, although it may be beneficial for avoiding complexity increase to support frequent switching, we think some discussion is necessary on the value of minimum switching gap, i.e., whether the gap of 14 symbols duration is appropriate or not and which SCS should be assumed. In the current specification, the UE does not expect to perform more than one uplink switching in a slot with *µUL* = max(*µUL, 1, µUL, 2*), where the *µUL, 1* corresponds to the subcarrier spacing of the active UL BWP of one uplink carrier before the switching gap and the *µUL, 2* corresponds to the subcarrier spacing of the active UL BWP of the other uplink carrier after the switching gap. So, there is already such restriction to ensure the minimum switching gap, and if the minimum gap requirement of 14 symbols duration is applied to the gap between the end of the last switching period and the beginning of the upcoming switching period, available resource for UL transmission after the switching period within a slot may be reduced. |

Based on above, the situation can be summarized as below.

### Summary 4.6

|  |
| --- |
| * Support/Supportive for defining minimum switching interval
	+ [11], [18], [19]
	+ Not expect to perform more than one UL switching in a slot based on largest SCS among all configured bands: [11]
	+ can perform UL switching only after 14 symbols or later: [18]
	+ minimum required duration between two consecutive updates of band pair for Alt.2: [19]
* Not support/supportive
	+ [20]
	+ Current restriction on no more than one UL switching in a slot based on larger SCS can ensure minimum switching gap [20]
 |

The moderator would like to ask companies to provide feedback if any on the above summary and companies proposals.

|  |  |
| --- | --- |
| Company | Comment |
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1. Discussions on the target scenarios, general assumptions and others for Rel-18 multi-carrier UL Tx switching

At the RAN#96 meeting, RAN guidance on the target scenarios for study on Rel-18 multi-carrier UL Tx switching in Q3 2022 was agreed. In this section, companies’ observations and proposals on the target scenarios, general assumptions and others are summarized.

## 5.1 Views on Inter-band CA Option 1 (switched UL) and Inter-band CA Option 2 (dual UL)

In contributions, following observations and proposals were made for Inter-band CA Option 2 (dual UL).

|  |  |
| --- | --- |
| [2] ZTE | CA (including both intra-band CA and inter-band CA) has been commonly deployed in 5G, especially for operators who own more than one band. For UEs supporting 3 or 4 bands, to fully enjoy the benefits of configuring more UL bands than its simultaneous transmission capability, it is necessary to support 2 Tx simultaneous transmission on two bands instead of limiting to up to 1Tx simultaneous transmission on one band. In this sense, it is straightforward that UE supporting UL Tx switching schemes across up to 3 or 4 bands requires legacy inter-band CA as the prerequisite capability. In Rel-16/Rel-17, both Option1 (switched UL) and Option2 (dual UL) has been specified for UL Tx switching for CA. Among Option1 and Option2, Option2 should be prioritized to fully enjoy the benefits of configuring more UL bands than its simultaneous transmission capability.***Proposal 1****: UE supporting Rel-18 UL Tx switching schemes across up to 3 or 4 bands requires support of legacy inter-band CA for at least two of the bands.* ***Observation 1****: In order to fully enjoy the benefits of configuring more UL bands than its simultaneous transmission capability, it is beneficial to prioritize CA (especially CA Option2) for Rel-18 UL Tx switching across up to 3 or 4 bands.* |
| [3] SPRD | For Alt.1, dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission, it can support both of Option 1 *'switchedUL'* and Option 2 *'dualUL'* of mapping between UL transmission ports and Tx chains. Which one to support still up to UE capability signalling and configuration, as same as Rel-16/17. And UE is not expected to transmit during the uplink switching gap when there is a state of Tx chain changing. One carrier in one band, or two contiguous carrier in only one band can be considered based the conclusion in RAN#96. 1. ***When Alt 1 applies for Rel-18 UL Tx switching among 3 bands or 4 bands, including:***
* ***Support Option 1 and Option 2 of mapping between UL transmission ports and Tx chains.***
* ***UE is not expected to transmit during the uplink switching gap when there is a state of Tx chain changing.***
 |
| [4] vivo | **Proposal 2: The Tx switching between different cases for 3 or 4 bands can at least include these scenarios that are almost identical to the Tx switching cases between 2 bands specified in Rel-16/Rel-17.*** **Scenario 1: Switching between the case of 1 Tx on band A and 1 Tx on band B, and the case of 0 Tx on band A and 2 Tx on band B, while 0Tx on band C (and band D if configured).**
* **Scenario 2: Switching between the case of 0 Tx on band A and 2 Tx on band B, and the case of 2 Tx on band A and 0 Tx on band B, while 0Tx on band C (and band D if configured).**
* **Scenario 3: Switching among the case of 1 Tx on band A and 1 Tx on band B, the case of 0 Tx on band A and 2 Tx on band B, and the case of 2 Tx on band A and 0 Tx on band B, while 0Tx on band C (and band D if configured).**

**Proposal 3: The following Tx switching between different cases for 3 or 4 bands can be studied in Rel-18:*** **Scenario 4: Switching between the case of 1 Tx on band A and 1 Tx on band B, and the case of 0 Tx on band A/B and 2 Tx on band C, (while 0Tx on band D if configured).**
* **Scenario 5: Switching between the case of 1 Tx on band A and 1 Tx on band B, and the case of 1 Tx on band A and 1 Tx on band C, (while 0Tx on band D if configured).**

**Proposal 4: The following Tx switching between different cases for 4 bands can be studied in Rel-18:*** **Scenario 6: Switching between the case of 1 Tx on band A and 1 Tx on band B, and the case of 1 Tx on band C and 1 Tx on band D.**

**Proposal 5: Option 1(*switchedUL*) and option 2 (*DualUL*) are both supported in Rel-18 Tx switching.** |
| [7] OPPO | ***Proposal 2: For inter-band UL CA option 1 with 3 or 4 carriers, R17 triggering mechanism can be reused to support Tx switch among 3 or 4 bands.*** ***Proposal 4: For inter-band UL CA option 2 with 3 or 4 carriers, the cases not covered by Rel-16/17, needs further discussion.***  |
| [8] CATT | **Proposal 1: For dynamic UL Tx switching in Rel-18, both Tx switching modes of option 1 (*SwitchedUL*) and option 2 *(DualUL)* should be supported for UL Tx switching across up to 3 or 4 bands.****Proposal 7: For uplink Tx switching across up to 3 or 4 bands, if the UE is configured with option 2 (*DualUL*) and only two carriers are involved in Tx UL switching, the uplink Tx switching scheme in Rel-16/Rel-17 can be reused.****Proposal 8: For uplink Tx switching across up to 3 or 4 bands, if the UE is configured with option 2 (*DualUL*) and three carriers are involved in Tx UL switching, the following two cases shall be applied uplink switching period** * **Switching between “2-port transmission on first uplink carrier” and “1-port transmission on second uplink carrier and 1-port transmission on third uplink carrier”**
* **Switching between “1-port transmission on first uplink carrier and 1-port transmission on second uplink carrier” and “1-port transmission on first or second uplink carrier and 1-port transmission on third uplink carrier”.**

**Proposal 9: For uplink TX switching across up to 3 or 4 bands, if the UE is configured with option 2 (DualUL) and four carriers are involved in Tx UL switching, the following one case shall be applied uplink switching period,*** **Switching between “1-port transmission on first uplink carrier and 1-port transmission on second uplink carrier” and “1-port transmission on third uplink carrier 1-port transmission on fourth uplink carrier.”**
 |
| [10] Intel | **Proposal 2*** If Rel-18 multi-carrier Tx switching is supported, for mapping between UL transmission ports and Tx chain:
	+ Consider Table 1 for Tx switching across 3 bands CA Option 1 without or with SUL
	+ Consider Table 2 for Tx switching across 3 bands CA Option 2 without SUL
	+ Consider Table 3 for Tx switching across 4 bands CA Option 1 without or with SUL
	+ Consider Table 4 for Tx switching across 4 bands CA Option 2 without SUL
 |
| [13] CT | **Proposal 3: For Rel-18 UL Tx switching across 3 bands each supporting maximum 2Tx chain, the mapping between Tx chains and UL transmission antenna ports for inter-band UL CA Option 1 with and without SUL is defined as follows.****Proposal 4: For Rel-18 UL Tx switching across 4 bands each supporting maximum 2Tx chain, the mapping between Tx chains and UL transmission antenna ports for inter-band UL CA Option 1 with and without SUL is defined as follows.****Proposal 5: For inter-band UL CA Option 1 with and without SUL, if Tx switching across 3 or 4 bands is configured, the switching period is only applicable when the UL transmissions are switched between different bands.****Proposal 6: For Rel-18 UL Tx switching across 3 bands each supporting maximum 2Tx chain, the mapping between Tx chains and UL transmission antenna ports for inter-band UL CA Option 2 without SUL is defined as follows.****Proposal 7: For Rel-18 UL Tx switching across 4 bands each supporting maximum 2Tx chain, the mapping between Tx chains and UL transmission antenna ports for inter-band UL CA Option 2 without SUL is defined as follows.****Proposal 8: For inter-band UL CA Option 2 without SUL, if Tx switching across 3 or 4 bands is configured, the switching period is applicable in the following cases:*** **If the current state of Tx chains is 2Tx on one band and 0Tx on other bands, the next UL transmission has a 2-port transmission on at least one carrier on one of other bands.**
* **If the current state of Tx chains is 2Tx on one band and 0Tx on other bands, the next UL transmission has simultaneous 1-port transmission on two bands each on at least one carrier.**
* **If the current state of Tx chains is 2Tx on one band and 0Tx on other bands, the next UL transmission only has a 1-port transmission on at least one carrier on one of other bands.**
* **If the current state of Tx chains is 1Tx on one band and 1Tx on another band, the next UL transmission has a 2-port transmission on at least one carrier on a band.**
* **If the current state of Tx chains is 1Tx on one band and 1Tx on another band, the next UL transmission has simultaneous 1-port transmission on two bands each on at least one carrier, at least one of the next transmitting two bands is different than the two current 1Tx bands.**
* **If the current state of Tx chains is 1Tx on one band and 1Tx on another band, the next UL transmission only has a 1-port transmission on at least one carrier on a third band.**
 |
| [18] QC | **Proposal 4: Adopt Table 3 for CA Option 1 without SUL mapping between Tx state and Tx layers.****Proposal 5: Adopt Table 5 for CA Option 2 without SUL mapping between Tx state and Tx layers.****Proposal 7: Adopt Table 7 for CA Option 1 with SUL mapping between Tx state and Tx layers.** |
| [19] Apple | Another aspect to consider is whether to support both the options for UL Tx switching for inter-band UL CA including switched UL and dual UL. Considering if Alt 2 is agreed to be supported, both options can be supported without any additional impact to the specifications. According to Alt, for the indicated pair from the configured 3 or 4 bands, both switched UL and dual UL can be supported. ***Proposal 4: RAN1 should agree to support both options including switched UL and dual UL for Alt 2 based UL Tx switching mechanisms in Rel-18*** |

Based on above, the situation can be summarized as below.

### Summary 5.1

|  |
| --- |
| * Both Option 1 and Option 2 should be supported
	+ [3], [4], [8], [19] (for Alt.2)
* Inter-band CA Option 2 should be prioritized
	+ [2]
* Switching cases should be defined for each scenario (3/4 bands, Option 1/2, with or without SUL) in a same/similar way with Rel-16/17
	+ [10], [13]
* Switching cases should be defined in a different way from Rel-16/17
	+ [18]
* New switching patterns (switching where more than 2 bands are involved) should be supported
	+ [8], [13]
* New switching patterns (switching where more than 2 bands are involved) should be studied
	+ [4], [7]
 |

The moderator would like to ask companies to provide feedback if any on the above summary and following potential FL proposal.

### **Proposed working assumption 5.1**

* If Rel-18 UL Tx switching is supported, both Inter-band CA Option 1 and Inter-band CA Option 2 are supported

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| Company | Comment |
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## 5.2 Views on how to solve ambiguous states issue

In contributions, following observations and proposals were made for ambiguous states issue.

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| --- | --- |
| [3] SPRD | Meanwhile, it needs to handle the case that the state of Tx chains after Tx switching is not unique for UL CA option 2 in the Table 3 and Table 4. Same method can be considered as Rel-17 UL Tx switching, a new RRC signalling is introduced for this purpose.1. ***RRC parameter can be used for resolving the ambiguous states.***
 |
| [4] vivo | Approach 1 lists all possible port-mapping combinations. However, the solution suffers from UE state ambiguity issue. More specifically, when a UE switches to a certain port-mapping combination if there is more than one Tx-chain combination supporting the port-mapping combination, the state of the target Tx chain is not unique, thus additional rules or configurations are needed to help the UE distinguish the Tx chain state, resulting in higher signalling overhead and UE complexity. Furthermore, this issue becomes worse for 4 bands Tx switching.Approach 2 to some extent mitigates the uncertainty issue since the number of port-mapping combinations is reduced and is simpler for UE implementation compared with Approach 1, but there is still ambiguity for switching between some cases.For Approach 3, the 2Tx-chains state can only be mapped to 2-ports transmission on a band. Compared with Approach 1 and Approach 2, the uncertainty issue is resolved as the Tx chain state is unique for every port-mapping combination. However, when UE transmitted with 2TX on one band is scheduled to perform 1 port transmission on the same band, it must switch to <1T+1T> Tx chain state because the combination of <0T+2T> does not support 1-port transmission, which leads to unnecessary interruption and more frequent Tx switching.For Approach 4, the 2Tx-chains state only applies to option 1. One potential issue of Approach 4 is that UE may not support 2 TX for some bands, and thus these bands cannot be scheduled as case 2 – case 4.Generally, we propose to have further study on the four approachs for mapping between UL transmission and Tx chains.**Proposal 6: Further study is needed for the supported cases of mapping between UL transmission ports and Tx chains.** |
| [8] CATT | If the value of RRC parameter is configured as ‘twoT’, UE can determine unique state to switch. If the value of RRC parameter is configured as ‘oneT’, there are still 3 possible candidate states. And gNB shall give further information to indicate which state to switched, which can be further study.**Proposal 11: For ambiguity switching cases issue, RRC parameter (e.g. uplinkTxSwitching-DualUL-TxState) can be re-used.*** **If the parameter is configured as twoT, no further indication is needed.**
* **If the parameter is configured as oneT, gNB shall give further indication, detail is FFS.**
 |
| [11] Xiaomi | ***Observation 3: There may be ambiguity on determining the Tx chain state between two adjacent uplink transmissions in some cases, i.e. band pairs contains the same band on which single port transmission is allowed.***From UE perspective, it knows current operation state, i.e. the association of Tx chain and UL band. For example, it is clear to a UE that whether (1P+0P+0P+0P) is under operation state of case#1 or case#2. If the pending transmission happens on another band, e.g. band#2 or band#3, it can determine whether a switching period is needed or not accordingly. There are many combinations need to be described or specified in order to avoid ambiguity, a unique solution is preferred. ***Observation 4: UE is aware of its operation state and can determine whether switching period is needed or not before a pending uplink transmission.*** |
| [13] CT | 3) If the current state of Tx chains is 2Tx on one band and 0Tx on other bands, the next UL transmission only has a 1-port transmission on at least one carrier on one of other bands.The state of Tx chains after Tx switching is not unique in this case similar as in Rel-17. For instance, if the current state of Tx chains is 2T+0T+0T for 3 bands Tx switching and the next UL transmission is 1-port transmission on band B, since 0P+1P+0P can be mapped to either 0T+2T+0T or 1T+1T+0T or 0T+1T+1T, then what’s the state of Tx chains after Tx switching? Another example, if the current state of Tx chains is 2T+0T+0T+0T for 4 bands Tx switching and the next UL transmission is 1-port transmission on band B, since 0P+1P+0P+0P can be mapped to either 0T+2T+0T+0T or 1T+1T+0T+0T or 0T+1T+1T+0T or 0T+1T+0T+1T, then what’s the state of Tx chains after Tx switching? Since this issue was solved by RRC configuring the state of Tx chains after Tx switching in Rel-17, the same principle could also be reused in Rel-18. To be band agnostic, RRC can configure the UE to consider this as if 1-port transmission was transmitted on both current 2Tx band and the next transmitting band, or the UE to consider this as if 2-port transmission on the transmitting band.6) If the current state of Tx chains is 1Tx on one band and 1Tx on another band, the next UL transmission only has a 1-port transmission on at least one carrier on a third band.This case also has multiple state of Tx chains after Tx switching. An example is if the current state of Tx chains is 1T+1T+0T for 3 bands Tx switching and the next UL transmission is 1-port transmission on band C, since 0P+0P+1P can be mapped to either 0T+0T+2T or 1T+0T+1T or 0T+1T+1T, then what’s the state of Tx chains after Tx switching? Another example for 4 bands Tx switching is if the current state of Tx chains is 1T+1T+0T+0T and the next UL transmission is 1-port transmission on band C, since 0P+0P+1P+0P can be mapped to either 0T+0T+2T+0T or 1T+0T+1T+0T or 0T+1T+1T+0T or 0T+0T+1T+1T, then what’s the state of Tx chains after Tx switching? As a band agnostic way, RRC can configure the UE to consider this as if 1-port transmission was transmitted on both the next transmitting band and one of current 1Tx band, or the UE to consider this as if 1-port transmission was transmitted on both the next transmitting band and the other of current 1Tx band, or the UE to consider this as if 2-port transmission on the transmitting band.**Proposal 9: Reuse the Rel-17 RRC configuration principle to address the issue that the state of Tx chains after Tx switching may not be unique.** |
| [17] LG | (1) In a state where two Tx chains are on band A, when 1-port UL transmission occurs in band B, the UL Tx switching between band A and band B can be triggered. However, in this case, it is necessary to clarify whether both of two Tx chains on band A are switched to band B or only one Tx chain is switched while the other Tx chain is remained on band A.**Proposal #2: Discuss on the following ambiguous case*** + - **When two Tx chains are on band A, if 1-port UL transmission is scheduled in band B, the UL Tx switching between band A and band B is occurred. In this case, it is necessary to clarify whether both of two Tx chains on band A are switched to band B or only one Tx chain is switched to band B while the other Tx chain is still remained on band A.**

(2) In a state where one Tx chain is on band A and another Tx chain is on band B, when 1-port UL transmission occurs on band C, the UL Tx switching between band C and band A (or B) may be triggered. However, in this case, it is necessary to clarify which of Tx chain on band A or Tx chain on band B is switched to band C.**Proposal #3: Discuss on the following ambiguous case*** + - **When one Tx chain is on band A and another Tx chain is on band B, if 1-port UL transmission is scheduled on band C, the UL Tx switching between band C and band A (or B) is occurred. In this case, it is necessary to clarify which of Tx chain on band A or Tx chain on band B is switched to band C.**
 |
| [21] E/// | Lastly, for any ambiguity to support dynamic UL Tx switching across 3 or 4 bands, we propose to adopt Rel-17 approach and resolve the ambiguity via RRC configurations.1. To support dynamic UL Tx switching across 3 or 4 bands, resolve any ambiguity in TX chains state transition via RRC configurations (similar to Rel-17).
 |
| [22] Google | In Rel. 17, RRC parameter *uplinkTxSwitching-DualUL-TxState-r17* was introduced to resolve the ambiguity cases between antenna states and antenna port combinations, for example, in Table 1, the antenna port combination C1 may apply to antenna states case 1, case 4, and case 6. Likewise, in Table 2, the antenna port combination C1 may apply to case 1, case 2, case 8, and case 9. Because the Rel. 17 RRC parameter *uplinkTxSwitching-DualUL-TxState-r17* can only resolveambiguity between 2 cases, new method or indication should be introduced if 3 and 4 bands UL Tx switching is supported.**Proposal 2: Study the Tx chains state indication for the case that the state of Tx chains after the UL Tx switching is not unique, if 3 and/or 4 bands UL Tx switching is supported.** |

Based on above, the situation can be summarized as below.

### Summary 5.2

|  |
| --- |
| * RRC signaling can be used to solve the ambiguous states issue
	+ [3], [8], [13], [21]
* Limiting the supported cases of mapping between UL transmission ports and Tx chains should be studied
	+ [4]
* Study on new method or indication is needed
	+ [11], [17], [22]
 |

The moderator would like to ask companies to provide feedback if any on the above summary and companies proposals.

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| Company | Comment |
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## 5.3 Views on switching configurations

In contributions, following observations and proposals were made for switching configurations.

|  |  |
| --- | --- |
| [3] SPRD | For switching configurations, it gives some restrictions on the number bands that support 2Tx bands. Table 1 is an example that only 2 bands out of 3 bands support up to 2Tx. Band1 only support 1Tx, and Band2 and Band 3 can support 2Tx. So the switching configurations are appropriate for different band combinations. Such as for some bands configurations, only one band can support 2Tx, but for another bands, two bands can be configured as 2Tx. It is a universal method, and easily applied for UL Tx switching configurations. In addition, UE capability can be used together with the switching configurations, to provide additional information for gNB to decide the number of 2Tx bands and which subset bands can be configured as 2Tx. 1. ***It is proposed to support the switching configurations in the observation from RAN1#109e.***
2. ***UE capability can be used together with the switching configurations, to provide additional information for gNB to decide the number of 2Tx bands and which subset bands can be configured as 2Tx.***
 |
| [4] vivo | To ensure the full flexibility of UE implementation, options in observation 2 should not be excluded. For example, if only the switching configuration 3-1 and 4-1 are supported, a band supporting only 1 Tx cannot be involved in UL Tx switching.**Proposal 7: All the switching configurations for 3 and 4 bands should not be excluded considering the flexibility of UE implementation.** |
| [15] CMCC | It is commented that the switching configuration should be considered due to the potential complexity when fully dynamic Tx switching across 3 or 4 bands is enabled. According to the motivation of the WI on multi-carrier enhancement, it is important to ensure the available scattered spectrum bands or wider bandwidth spectrum can be utilized in a more spectral/power efficient and flexible manner, which may potentially lead to higher UL data rate, spectrum utilization and UL capacity. From our perspective, to make full use of the scattered spectrum bands, there is no need to limit only 1Tx transmission on one or more certain bands in the specification, which can just depend on UE and gNB implementation.**Proposal 2. For any switching mechanism, both of two Tx chains can switch to any of 3 or 4 bands to provide scheduling flexibility and performance improvements.** |
| [20]DCM | In our understanding, above proposals can be considered as flexible support of switching configuration(s). In other words, allowing flexible support of concurrent UL case(s) and/or MIMO capability for each band/CC would mean that UE can support Rel-18 UL Tx switching even if the switching configuration of the UE is different from 3-1/4-1, and the switching configurations 3-2/3-3 (4-2/4-3/4-4) would have lower complexity than 3-1 (4-1). |

Based on above, the situation can be summarized as below.

### Summary 5.3

|  |
| --- |
| * Support/supportive to support all switching configurations
	+ [3], [4]
* Not support/supportive to support all switching configurations
	+ [15]
 |

The moderator would like to ask companies to provide feedback if any on the above summary and companies proposals.

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| Company | Comment |
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## 5.4 Views on scenarios with intra-band contiguous carriers

In contributions, following observations and proposals were made for scenarios with intra-band contiguous carriers.

|  |  |
| --- | --- |
| [2] ZTE | ***Observation 4****: If Alt.1 is adopted, all the 32 different combinations should be considered for Rel-18 UL Tx switching across 3/4 bands.** *The 12 combinations for 3-band case: {A3-1, B3-1}, {A3-2, B3-1}, {A3-3, B3-1}, {A3-4, B3-1}, {A3-1, B3-2}, {A3-2, B3-2}, {A3-3, B3-2}, {A3-4, B3-2}, {A3-1, B3-3}, {A3-2, B3-3}, {A3-3, B3-3}, {A3-4, B3-3}.*
* *The 20 combinations for 4-band case: {A4-1, B4-1}, {A4-2, B4-1}, {A4-3, B4-1}, {A4-4, B4-1}, {A4-5, B4-1},{A4-1, B4-2}, {A4-2, B4-2}, {A4-3, B4-2}, {A4-4, B4-2}, {A4-5, B4-2}, {A4-1, B4-3}, {A4-2, B4-3}, {A4-3, B4-3}, {A4-4, B4-3}, {A4-5, B4-3},{A4-1, B4-4}, {A4-2, B4-4}, {A4-3, B4-4}, {A4-4, B4-4}, {A4-5, B4-4}.*

Figure 4 Scenarios of different Combinations (number of Tx per band, number of carriers per band) |
| [13] CT | Since there could be one or some of the bands not supporting up to 2Tx, and intra-band two contiguous aggregated carriers within a band out of 3 or 4 bands, some companies thought the Tx chain antenna ports mapping cases are too many, and the switching cases are too complex to be specified. However, we think the number of mapping and switching cases to be discussed is not as many as it seems. The switching configuration that each band supporting maximum 2Tx chain has the universal set of mapping and switching cases, which should be discussed firstly. Other switching configurations for band(s) not supporting up to 2Tx do not bring more switching cases. If one band has two contiguous aggregated carriers, in Rel-17 Tx switching, the same state of Tx chain is applied to the intra-band contiguous carriers within the band. For Rel-18 UL Tx switching across up to 3 or 4 bands, the same mechanism can be used for intra-band CA carriers. UL Tx switching only occurs when the current and previous UL transmission involve different bands.**Proposal 1: For Rel-18 UL Tx switching across up to 3 or 4 bands, the same state of Tx chain is applied to the intra-band two contiguous carriers within a band.** |
| [15] CMCC | Besides, in the CA scenarios with intra-band two contiguous aggregated carriers within one non-SUL band out of 3 or 4 bands, the mapping between UL transmission ports and Tx chains of such cases can be similar to Rel-17 2Tx-2Tx switching between 1 carrier on Band A and 2 contiguous carriers on Band B. |
| [19] Apple | In RAN1#109-e, there has been discussion on extension of intra-band CA with UL Tx switching. In Rel-17, it is allowed to have 1 band with up to 2 contiguous carriers. In Rel-18, if it is agreed to increase the bands to 3 or 4, then it needs to be agreed whether any further extension such as increasing the number of contiguous carriers within one band and/or increasing number of bands with multiple contiguous carriers is within the scope of Rel-18 or not. In our view, as there is no discussion on potential extension of intra-band CA in Rel-18’s WID, so no enhancement should be considered on this aspect. At least with Alt 2, it should be quite straightforward to agree that the band pair that is indicated can have only 1 band with up to contiguous carriers and therefore, no further enhanced is needed compared to Rel-17.***Proposal 6: RAN 1 should agree to support only up to 1 band with up to 2 contiguous carriers for a band pair that is indicated for dynamic UL Tx switching with Alt 2 based switching mechanism**** ***No enhancement needed for intra-band CA with Alt 2 based UL Tx switching compared to Rel-17***
 |

Based on above, the situation can be summarized as below.

### Summary 5.4

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| * The same state of Tx chain is applied to the intra-band two contiguous carriers as in Rel-17
	+ [13], [15], [19] (for Alt.2)
* Scenarios with intra-band contiguous carriers are considered as different combinations
	+ [2]
* Support only up to 1 band with up to 2 contiguous carriers for a band pair in Alt.2
	+ [2]
 |

The moderator would like to ask companies to provide feedback if any on the above summary and companies proposals.

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| Company | Comment |
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## 5.5 Views on PUCCH cell

In contributions, following observations and proposals were made for PUCCH cell.

|  |  |
| --- | --- |
| [15] CMCC | Another issue is the configuration of PUCCH cell for Rel-18 UL Tx switching across 3 or 4 bands. In current NR design, PUCCH can be only configured on sPCell or PUCCH-SCell, when UE Tx is switched to the carrier/band corresponding to a cell without PUCCH resource configuration, this will result in an ambiguity on which cell the PUCCH can transmit. Thus, the PUCCH cell configuration for UL Tx switching needs to be further studied, and we think the following options can be considered.* Option 1. Depending on gNB’s implementation to guarantee UE’s Tx switch to the carriers/bands corresponding to the cell configured with PUCCH.
* Option 2. Multiple PUCCH cells can be pre-configured.

The first option is up to gNB implementation to guarantee UE’s Tx has been switched to sPCell or PUCCH-SCell in the slot UE needs to feedback HARQ-ACK, which can avoid UE’s Tx switch to a cell not configured with PUCCH. But this will reduce the spectrum utilization due to UE’s Tx must be switched to specific UL carrier/band in such HARQ-ACK feedback slot even other carriers/bands could provide better transmission conditions.In Option 2, multiple PUCCH cells can be pre-configured and UE can determine one cell to transmit PUCCH in any Tx switching scenarios. For example, all three or four carriers can be configured with PUCCH resource with some priority or order and UE can determine the carrier to transmit PUCCH according to the pre-defined order and the carriers Tx has been switched on. In this way, all configured bands can be used for UL Tx switching without additional restrictions, and there is no impact on UL data rate. Thus it is recommended that multiple PUCCH cells can be configured for UE UL Tx switching across 3 or 4 bands to ensure better spectrum utilization of UL transmissions.**Proposal 3. Multiple PUCCH cells can be configured for Rel-18 UL Tx switching across 3 or 4 bands.** |

The moderator would like to ask companies to provide feedback if any on the above proposal.

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| Company | Comment |
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## 5.6 Views on switching period

In contributions, following observations and proposals were made for switching period.

|  |  |
| --- | --- |
| [5] Sony | When it comes to the switch duration, an LS was sent to RAN4 for further clarification. From our internal investigation the switch duration is proportional to the frequency difference the UE need to switch, rather than the number of carriers. Further, the switch duration is caused by the PLL and the lock-in time depend on how far the VCO needs to be tuned. In any case, in our opinion, this seem to be an implementation issue, and multiple solutions to achieve a lower settling time are available, e.g. current injection techniques or the use of multiple PLLs. As a compromise, it would be wise to continue the support of various UE implementations and as the UE already in Rel-17 indicate the duration for Tx switching among various band combinations. This will allow the gNB to schedule accordingly.**Observation 3: Switch duration between frequency carriers appears to be implementation specific and is already in Rel-17 shared as a capability.****Proposal 2: Unless RAN4 conclude that switch duration is a problem, we encourage 3GPP to continue this work.** |
| [10] Intel | At the RAN1#109-e meeting, it was agreed to send an LS to RAN4 on the feedback for potential increase of switching period and UE complexity [1]. Note that for Rel-18 multi-carrier Tx switching scheme across 3 or 4 bands for uplink transmission, if UE needs to carry out any other operations than mere RF chain power ramping up, e.g., UE may need to load certain parameters into RF network before it actually performs dynamic Tx switching in case more than two bands are activated, longer Tx switching period may be expected compared to what was defined in Rel-16/17. **Observation 1*** For Rel-18 multi-carrier Tx switching scheme, longer Tx switching period may be expected compared to what was defined in Rel-16/17, if UE needs to carry out any other operations than mere RF chain power ramping up.

Note that the Rel-18 multi-carrier Tx switching scheme can be beneficial when Tx switching period is much less than RRC reconfiguration of 2 bands for uplink transmission. Otherwise, larger interruption on the uplink transmission due to Tx switching may result in undesirable performance degradation. Hence, in our view, further investigation is needed to identify the benefit of dynamic Tx switching across 3 or 4 bands, with the consideration of the Tx switching period based on the feedback from RAN4. **Proposal 1*** RAN1 to further study the benefit of Tx switching across 3 or 4 bands with the consideration of the Tx switching period from RAN4.
 |
| [16] MTK | **Switching period:** Unlike R16/R17 UL Tx switching, in R18 the Tx switching will be among more than two bands. This will require more complex implementation on the UE side and, larger switching period might be required compared to R16/R17 switching period.1. ***For UL Tx switching among 3/4 bands, the required switching period is reported separately from R16/R17 switching period.***

Table 3 compares the evaluation results of 2-CC and 4-CC UL 2TX switching. It can be observed that the throughput gain highly depends on the switching period. When UE can support switching period of 140 us, there can provide 17.68% throughput gain. On the other hand, if switching period of 210 us is required, the throughput gain reduces to less than 10%. Thus, we have the following observation and proposal.1. ***The benefit provided by UL 2TX switching over 4 bands highly depends on the achievable switching period. If supporting dynamic switching over more bands causes significant increment in the switching period/gap, there can only less than 7% gain w.r.t. UL TX switching over 2 bands.***

Table 3: Simulation results of 2-CC/4-CC UL 2-TX switching.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Baseline: 2-CC UL 2-TX switching; switching period = 35 us | Enh1: 4-CC UL 2-TX switching; switching period = 140 us | Enh2: 4-CC UL 2-TX switching; switching period = 210 us |
| Average user T-put (Mbps)  | 52.93 | 62.29 | 56.34 |
| T-put gain (%)  | - | 17.68% | 6.45% |

 |

As RAN1 sent a LS to RAN4 to ask their feedback on switching period at the last meeting, the moderator would like to wait for the RAN4 feedback and postpone the discussion in RAN1 on the switching period.

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## 5.7 Views on scenarios with multiple TAGs

In contributions, following observations and proposals were made for scenarios with multiple TAGs.

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| [19] Apple | Depending on the discussion and outcome in RAN4, it can be further considered in RAN1 if any additional limitation related to multiple TAGs is needed or not. In our view, at least for 3 or 4 bands, if agreed, and if Alt 2 is adopted for switching mechanism, then RAN1 can consider the restriction to allow indication of band pair belong to same TAG. Basically, if RAN4 agrees to introduce multiple TAGs, at least for 3 or 4 bands, then RAN1 can allow indicating band pair belonging to same TAG with Alt 2 based mechanism. This would ensure no additional impact is necessary, at least from RAN1 perspective. ***Proposal 8: RAN1 can consider limiting the indicated bands pair belonging to same TAG with Alt 2 based switching mechanism**** ***If and how multiple TAGs are supported for 3 or 4 bands is still up to RAN4***
 |

As RAN1 concluded that RAN1 can discuss multiple TAGs only if triggered by RAN4, the moderator would like to avoid any discussion on multiple TAGs before receiving RAN4 trigger.

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## 5.8 Views on scenarios to be checked in RAN#97-e

In contributions, following observations and proposals were made for scenarios to be checked in RAN#97-e according to the RAN guidance [24].

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| [2] ZTE | Although the following two items won’t be discussed in this RAN1 meeting based on the RAN guidance, we provide some preliminary analysis for these two scenarios.* + - {SUL band + corresponding NUL band} + {SUL band + corresponding NUL band}
		- Simultaneous transmission across 2 bands in {SUL band + corresponding NUL band} + 1 or 2 other NUL band(s) (excluding simultaneous transmission between SUL and corresponding NUL)

Regarding the first bullet, i.e., ‘CA+2SUL’, its motivation is not clear to us. Based on our understanding, it only exists in the 4 bands case. In this case, there are 2 cells and each of the cell contains one SUL. In total, there are two SUL carriers. If UE can already support CA since CA is the prerequisite capability for UL Tx switching schemes across up to 3 or 4 bands, the benefits or motivations to support ‘CA+2SUL’ is not clear to us. More justification is needed. In addition, RAN1 has never discussed this 2 SUL case before. From our perspective, this is trying to extend the SUL framework. Furthermore, this case only exists for the 4 bands case, which is conflicting with the requirement of defining a common solution for 3 bands case and 4 bands case as noted in the WID. In addition, as discussed in the RAN plenary, the current RAN4 spec doesn’t support ‘CA+2SUL’. More discussion is needed for this new scenario.Regarding the second bullet, ‘CA Option2 + SUL’, SUL is not allowed to transmit with NUL simultaneously based on the existing specification. If simultaneous transmission of SUL and NUL is introduced in Rel-18, the RAN4 requirements framework may have to be redesigned. In addition, the functionality of ‘CA Option2 + SUL’ can already be supported by CA Option2, it is not clear about the motivation to introduce such a complicated scenario.***Observation 2****: The motivation of introducing the following two new scenarios is not clear and new frameworks/requirements are needed if they are introduced.* * + - *{SUL band + corresponding NUL band} + {SUL band + corresponding NUL band}*
		- *Simultaneous transmission across 2 bands in {SUL band + corresponding NUL band} + 1 or 2 other NUL band(s) (excluding simultaneous transmission between SUL and corresponding NUL)*
 |
| [8] CATT | Compared with the mapping rule for inter-band UL CA option 2 with 3 carriers, the configuration of antenna ports (1P+1P+0P) in the case 3 of Table 5 should be removed because the SUL-1 and NUL-1 cannot be scheduled or configured with UL transmission simultaneously, as same reason, the configuration of antenna ports (1P+1P+0P+0P) in the case 4 in Table 6 should be removed. From RAN1 view, it can be regarded that only sub-set switching cases are supported according to UE capability reporting or gNB configuration.For SUL scenario, if the UE is configured with option 2 (*DualUL*), the UE will be not expected to be scheduled or configured with UL transmission simultaneously on SUL and corresponding NUL band. For this reason, the configuration of antenna for co-current transmission shall be removed, From RAN1 view, the 2 SUL configuration can be regarded that only sub-set switching cases are supported according to UE capability reporting or gNB configuration.**Proposal 6: From RAN1 perspective, following SUL configurations will not introduce extra switching cases for Rel-18 UL Tx switching. Whether it is supported or not depends on RAN4.*** **{SUL band + corresponding NUL band} + {SUL band + corresponding NUL band}.**
* **Simultaneous transmission across 2 bands in {SUL band + corresponding NUL band} + 1 or 2 other NUL band(s) (excluding simultaneous transmission between SUL and corresponding NUL).**
 |
| [9] NOK, NSB | The Rel-16/Rel-17 specifications define separately switching for CA and switching for SUL. Introducing support for a switching combination where both CA and SUL exist (either of the two cases mentioned in the RAN guidance) would lead to needing to introduce another flavour of UL Tx Switching for a combined CA+SUL uplink Tx switching scenario. The implications of this depend on the CA switching mechanism adopted for the 3- or 4-band UL Tx Switching, hence it is not possible to assess the compatibility or additional work needed for the CA+SUL combination before the CA case has gained more maturity**Proposal 5:** Postpone the discussion on the UL Tx Switching with a SUL cell in a CA configuration until after UL Tx Switching for 3 or 4 bands in the CA configuration has gained more maturity |
| [13] CT | For inter-band UL-CA Option 1, since UE cannot be scheduled or configured with UL transmission on different bands simultaneously, the switching mechanism is the same no matter one or two SUL bands are configured.For inter-band UL-CA Option 2 configuring one or two SUL bands, UE cannot be scheduled or configured with UL transmission on NUL and SUL bands belonging to one cell simultaneously. Supporting simultaneous UL transmission on other different bands would not bring additional switching cases. The switching cases are a subset of the cases for inter-band UL CA Option 2 without SUL scenario.**Observation 3: From RAN1 perspective, supporting two SUL bands configuration, and supporting simultaneous transmission across 2 bands in {SUL band + corresponding NUL band} + 1 or 2 other NUL band(s) (excluding simultaneous transmission between SUL and corresponding NUL) would not bring additional switching cases for Rel-18 UL Tx switching.** |
| [18] QC | **Proposal 1: Following RAN#96 guidance, RAN1 #110 only focus inter-band UL CA Option 1 and 2 without SUL, and inter-band UL CA Option 1 with 1 SUL, and does not discuss other additional scenarios before further guidance.** |
| [19] Apple | In RAN#96, there has been discussion on whether additional scenarios with more than one SUL bands can be configured for 3 or 4 bands is within the scope or not [3]. Based on the outcome in RAN#96, it has been agreed that there can be potential discussion on inclusion of more than one SUL bands. Although, it is not expected to be discussed in RAN1#110, however, it is worth considering if and how the selection of Rel-18 UL Tx switching mechanism can impact the inclusion of more than 1 SUL band. In our view, if Alt 2 based switching mechanism is adopted, then it can be considered to include more than 1 SUL for the 3 or 4 configured bands. However, to avoid any additional specification consideration compared to Rel-16/17 (such as defining new switching cases with multiple SUL bands), it can be further considered to limit the number of SUL bands to one for the indicated pair in Alt 2 based switching mechanism. This provides a good trade-off to allow configuration of more than 1 SUL band, but limit the inclusion to only up to 1 SUL band within a pair, like Rel-16/17***Proposal 7: RAN1 can consider limiting the maximum number of SUL bands to one within the indicated bands pair with Alt 2 based switching mechanism**** ***RAN1 can further discuss during and after RAN#97 whether the maximum number of SUL bands that can be configured within 3 or 4 configured bands is one or more***
 |

Following the RAN guidance, the moderator would like to postpone the discussion on scenarios to be checked in RAN#97-e.

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1. Summary of proposals

TBD

1. Conclusion

TBD

Appendix 1: Latest WID objective [23]

2. Study and if necessary specify following enhancements for multi-carrier UL operation [RAN1, RAN2, RAN4]

* UL Tx switching schemes across up to 3 or 4 bands with restriction of up to 2 Tx simultaneous transmission for FR1 UEs, including mechanisms to enable more configured UL bands than its simultaneous transmission capability and to support dynamic Tx carrier switching across the configured bands for both single TAG and multiple TAGs configurations (RAN1, RAN4)
	+ UE capability and RRC configuration related signalling (RAN2)
	+ Note: strive for RAN1/2 design agnostic with the number of bands, i.e., common design between 3 and 4 bands
	+ Note: no additional TAG is introduced for UL transmission on a carrier without corresponding DL carrier
	+ Note: this objective does not target to extend the SUL framework to support more than 1 SUL for 1 NUL
	+ Note: Extension of TX switching for 2 bands to multiple TAG configurations is included in the scope. The work is limited to RAN4.
* Switching time and other RF aspects, and RRM requirements for above UL Tx switching schemes across up to 3 or 4 bands (RAN4)
	+ Note: Prioritize UL Tx switching across up to 3 bands is to be addressed first and then that for up to 4 bands can also be addressed

Appendix 2: RAN guidance at RAN#96 [24]

**RAN provides following guidance to RAN1/2/4.**

* **If Rel-18 UL Tx switching is supported,**
	+ **RAN1/2/4 shall focus on defining necessary mechanisms and requirements for UL Tx switching across 3 or 4 different bands in Q3 2022**
		- **Inter-band UL-CA Option 1 (i.e., switched UL) and Option 2 (i.e., dual UL) without SUL band**
		- **Inter-band UL CA Option 1 (i.e., switched UL) for {SUL band + corresponding NUL band} + 1 or 2 other NUL band(s)**
			* **UL CA framework where UL CA is performed between NULs according to current RAN4 specifications should not be changed**
			* **Note: switching across any band in this scenario is not precluded**
		- **Intra-band two contiguous aggregated carriers within one non-SUL band out of 3 or 4 bands**
	+ **Further check additional scenarios in RAN#97e, e.g.,**
		- **{SUL band + corresponding NUL band} + {SUL band + corresponding NUL band}**
		- **Simultaneous transmission across 2 bands in {SUL band + corresponding NUL band} + 1 or 2 other NUL band(s) (excluding simultaneous transmission between SUL and corresponding NUL)**
	+ **Mechanisms/requirements should not introduce restrictions on what were already supported in current specifications for UL Tx switching**

Appendix 3: RAN1 agreements/observations/conclusions at RAN1#109-e [25]

**Conclusion**

EN-DC cases are out of scope for Rel-18 UL Tx switching

**Conclusion**

UL only cell cases are out of scope for Rel-18 UL Tx switching

**RAN1 Observation**

Four contributions ([R1-2203136](file:///C%3A%5CUsers%5Cyouns%5COneDrive%5CDocuments%5C3GPP%5CRAN1%20tdocs%5CTSGR1_109-e%5CDocs%5CR1-2203136.zip), [R1-2204724](file:///C%3A%5CUsers%5Cyouns%5COneDrive%5CDocuments%5C3GPP%5CRAN1%20tdocs%5CTSGR1_109-e%5CDocs%5CR1-2204724.zip), [R1-2204909](file:///C%3A%5CUsers%5Cyouns%5COneDrive%5CDocuments%5C3GPP%5CRAN1%20tdocs%5CTSGR1_109-e%5CDocs%5CR1-2204909.zip), [R1-2205131](file:///C%3A%5CUsers%5Cyouns%5COneDrive%5CDocuments%5C3GPP%5CRAN1%20tdocs%5CTSGR1_109-e%5CDocs%5CR1-2205131.zip)) from three companies show their evaluation results on UL Tx switching across 3 or 4 bands at RAN1#109-e meeting.

* All evaluation results show the performance gain of UL Tx switching across 4 bands compared with UL Tx switching across 2 bands, assuming TDD bands with different TDD UL/DL configurations are included in 4 bands.
	+ Evaluation results in [R1-2203136](file:///C%3A%5CUsers%5Cyouns%5COneDrive%5CDocuments%5C3GPP%5CRAN1%20tdocs%5CTSGR1_109-e%5CDocs%5CR1-2203136.zip) show the performance gain of UL Tx switching across 4 bands compared with UL Tx switching across 3 bands.
	+ Evaluation results in [R1-2204724](file:///C%3A%5CUsers%5Cyouns%5COneDrive%5CDocuments%5C3GPP%5CRAN1%20tdocs%5CTSGR1_109-e%5CDocs%5CR1-2204724.zip) show that the performance gain of UL Tx switching across 4 bands compared with UL Tx switching across 2 bands depends on achievable switching period, and the longer switching period for UL Tx switching across 4 bands compared with UL Tx switching across 2 bands leads to reduction of the performance gain. Other evaluation results did not consider the impact of longer switching period for UL Tx switching across 4 bands compared with UL Tx switching across 2 bands.
	+ Evaluation results in 5131 observe that the gain highly depends on the scheduling mechanism.
	+ The range of performance gains shown in four contributions varies depending on the simulation assumptions.

**Agreement**

Companies are encouraged to investigate pros and cons of following possible mechanisms for dynamic Tx carrier switching across the configured bands, and RAN1 strives for the down-selection at RAN1#110

* Alt.1: Dynamic Tx carrier switching can be across all the supported switching cases by the UE and based on the UL scheduling, i.e., via UL grant and/or RRC configuration for UL transmission
* Alt.2: NW indicates 2 bands out of the configured bands (3 or 4 bands) via DCI or MAC-CE, and dynamic Tx carrier switching between indicated bands is same as Rel-17
* Alt.3: One anchor band is selected among configured bands (3 or 4 bands), and dynamic Tx carrier switching can be performed only from the anchor band to a non-anchor band and from a non-anchor band to the anchor band
* Note: Other mechanisms are not precluded

**Agreement**

Send LS to RAN4 to ask their feedback on the potential increase of switching period and complexity in the case of UL Tx switching across 3 or 4 bands

* In the LS, observations based on the evaluation results and alternative switching mechanisms discussed in RAN1 are captured for the information to RAN4
* In the LS, RAN1 also asks RAN4 feedback on whether following assumption can be considered as baseline UE assumption/behavior even in case of the UL Tx switching across 3 or 4 bands
	+ When one of the two Tx chains is triggered to switch from one band to another band, another Tx chain which is in any of bands is also not expected to be used for transmission during the switching period

LS is endorsed in R1-2205502.

**Conclusion**

If Rel-18 UL Tx switching is supported, following assumption is applied for Rel-18 UL Tx switching across up to 3 or 4 bands

* Only when the two Tx chains are linked to one NR band, the 2-ports UL transmission on the NR band is possible

**RAN1 Observation**

Following proposals to address the concern on UE/gNB complexity increase or scheduling restriction due to UL Tx switching across larger number of bands compared with Rel-16/17 are identified in contributions submitted at RAN1#109-e, and companies are encouraged to investigate pros and cons of the proposals so that one or some of them may be down-selected after the down-selection of the mechanism for dynamic Tx carrier switching across the configured bands

* UE can report the supports of only some of concurrent UL cases (combinations of 2 bands for concurrent UL transmissions)
* Switching across 0/1/2 ports is supported only for 2 configured bands out of 3 or 4 configured bands and other bands support switching across 0/1 port only
* Only switching across 0/1 port is supported across all configured bands when 3 or 4 bands are configured
* Prioritization rules between uplink carriers are specified
* No restriction on the UEs choice of MIMO capability on any of the bands/CCs involved in the UL Tx switching band combination is introduced
* After one RF state switch, the next RF state switch must occur after 14 symbols or later (FFS: which SCS is assumed for the symbol duration)
* Note: Other solutions are not precluded
* Note: each proposal assumes certain mechanism for dynamic Tx carrier switching across the configured bands, and hence some or all of the proposals may not be necessary depending on the down selection of the mechanism for dynamic Tx carrier switching across the configured bands

**Conclusion**

It is RAN1’s understanding that RAN4 should lead the discussion on UL Tx switching with multiple TAGs for both 2 bands case and more than 2 bands case

* For further discussion in RAN1 with regards to UL Tx switching with multiple TAGs, it will be discussed only if triggered by RAN4
* If it is decided to support UL Tx switching with multiple TAGs, it is RAN1's working assumption that the number of TAGs should be limited to up to 2

**RAN1 Observation**

Following possible switching configurations can be considered, and RAN1 may discuss if any of the following switching configurations need to be supported after making some progress on the discussion on the switching mechanism

* For 3 bands case
	+ Switching configuration.3-1: all the 3 bands support up to 2Tx
	+ Switching configuration.3-2: only 1 band out of 3 bands support up to 2Tx
	+ Switching configuration.3-3: only 2 bands out of 3 bands support up to 2Tx
* For 4 bands case
	+ Switching configuration.4-1: all the 4 bands support up to 2Tx
	+ Switching configuration.4-2: only 1 band out of 4 bands support up to 2Tx
	+ Switching configuration.4-3: only 2 bands out of 4 bands support up to 2Tx
	+ Switching configuration.4-4: only 3 bands out of 4 bands support up to 2Tx
* Note: The Spec should not restrict which Tx chain is fixed or switched across certain bands.