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Title: Frame Structure and Numerology for New RAT

Agenda item: 8.1.5

Document for: Discussion and Decision

1. Introduction

A new radio access technology (RAT) will be developed to support a diverse set of use cases and deployment scenarios for IMT-2020 and beyond [1],[2]. It is envisioned that the new radio will support much larger aggregated bandwidths, operate in higher frequency bands and deliver significantly higher peak data rates compared to LTE. Furthermore, consistency in user experience is expected even in the most challenging scenarios. In this contribution, we discuss a flexible frame structure that can accommodate these usage scenarios, and associated deployment scenarios, in an efficient manner.

2. Background

The LTE RAT was primarily designed to support a wide area network and provide reduced user- and control-plane latency compared to WCDMA/HSPA. Although LTE has evolved from an initial focus on macro coverage to network densification with small cells, its basic frame structure and numerology places constraints on advanced features for new market needs because backward compatibility must be preserved. In contrast, the frame structure and numerology for the New Radio (NR) must be flexible enough to support a variety of use cases and frequency bands. The NR requirements in [1] lists several challenging requirements including:

1. Uplink and downlink user plane latency of 1ms for Ultra Reliable and Low Latency Communications (URLLC), and 4ms for enhanced Mobile Broadband (eMBB)
2. Operation at sub 6GHz and also in the ranges 24 – 40GHz and 66 – 86 GHz.
3. High speed train scenarios with maximum speeds up to 500 km/h at 4GHz and 30GHz
4. Aggregated bandwidths from 200MHz up to 1GHz.
5. Peak data rates of 20Gbps for DL and 10Gbps for UL

It should be immediately clear that, at least for URLLC, a shorter TTI duration is required to meet the latency target. On the other hand, for other traffic types, such as eMBB, with less stringent delay requirements it should be possible to employ longer data frames in order to use system resources more efficiently. Moreover, it is desirable that the NR frame structure and numerology is flexible enough for operation in all frequency ranges to justify investments in a new RAT. Thus, operation below 6GHz may require consideration of comparable TTI durations to LTE. In the next section we elaborate on flexible frame structure and numerology for the NR.

3. Frame Design for New Radio

3.1 Properties

In order to appropriately support the use cases described in [1], the frame design for the NR should have, among others, the following properties:

- Efficient support of higher frequency bands. To that effect, the new frame design should:
  - Efficiently support high Doppler spread originating from a much higher carrier frequency and/or high mobility scenarios.
  - Efficiently support increased phase noise and carrier frequency offsets, originating in local oscillators operating at higher frequencies.
- Efficient multiplexing of small packets with very low latency to support URLLC traffic, as well as large packets to support eMBB traffic with less stringent delay requirements.
- For TDD, flexible UL/DL configurations, including support for reduced latency.

In the following section we propose some design aspects of the NR frame addressing these properties.

3.2 Waveform Numerology

Waveform numerology is a fundamental aspect that can have a significant impact on the efficiency and performance of the NR. Sub-carrier spacing must take into account several propagation and transceiver design aspects, namely: delay spread and Doppler spread of the channel, cell size, and phase noise originating at the local oscillator. Current LTE sub-carrier spacing may be inappropriate for some of the use cases and deployment scenarios described by 3GPP in [1]. For the indoor and dense urban scenarios, a carrier frequency of 30GHz, increases the Doppler by a factor of 10 compared to LTE. A simple implementation may be to proportionally scale the subcarrier spacing and cyclic prefix by the same factor so that the Doppler effect is same as LTE today. Note that this also implies that the typical channel delay spread should be 10x smaller to maintain the same transmission efficiency with respect to the cyclic prefix overhead. On the other hand, for operation at sub 6GHz, where LTE operates, it is desirable to use similar numerology as LTE to simplify implementation for mixed-RAT operation. Therefore, a configurable numerology should be considered for the NR.

3.3 Frame Structure

The frame structure for the NR must be flexible enough to support a variety of use cases and frequency bands. While services envisioned for the URLLC use case demand minimal air interface latency, eMBB, services, which are expected to represent the vast majority of traffic carried by 5G networks, must be provided with extreme efficiency. In recent studies, [3], 3GPP has recognized several tradeoffs with varying the size of the LTE Transmission Time Interval (TTI). It has been observed that, while a shortened TTI may provide a clear latency advantage, it may also result in increased control and reference signaling overhead, as well as increased scheduling complexity. Moreover, short TTI transmissions are more vulnerable to time-varying fading, which can reduce transmission reliability and result in a higher retransmission rate, which in turn increases latency and introduces undesirable latency jitter.

A flexible frame structure, with variable TTI length and numerology, could enable the NR to efficiently support all use cases and deployment scenarios. The following aspects could be considered in order to define a variable TTI size:

- For latency critical traffic, network control information (e.g. channel state information feedback, or HARQ responses) and other reduced size packets, a short TTI may be defined.
- For throughput intensive traffic, such as eMBB, a longer TTI size may be defined, which reduces the associated control and reference signal overheads, and can take advantage of time diversity present in the channel. A longer TTI may also be used in high mobility scenarios, where exploiting the inherent time diversity of the channel can greatly increase transmission reliability.

A waveform that can exploit the time diversity of the channel, such as OTFS, described in [4], [5], may be particularly effective at maximizing the performance of a flexible TTI scheme. This concept is illustrated in Figure 1, where different TTI lengths are superimposed to a spectrogram of the channel, displaying its time variability. In this figure, the spectrogram of an ETU-300 channel is displayed. As it can be seen, a longer TTI can better exploit temporal variability and result in higher diversity and performance.

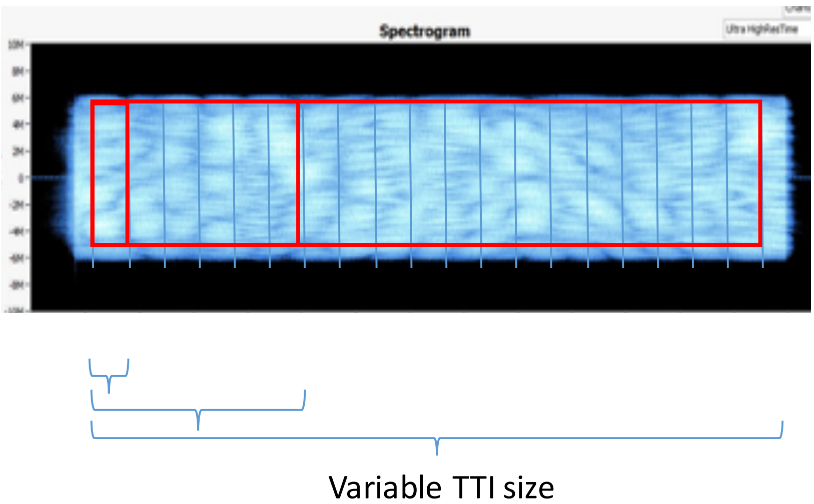

Figure 1. Spectrogram of the channel, representing its time and frequency variability. In the figure, channel variability is displayed along the time (horizontal) and frequency (vertical) dimensions. Lighter color indicates better channel quality.

Possible implementations of a variable TTI include:

- Scaling of sub-carrier spacing: In order to accommodate low and high frequency bands, it may be desirable to adapt the numerology (sub-carrier spacing and symbol duration) for each frequency band. By allowing sub-carrier spacing to scale with channel and transceiver effects, such as Doppler spread and phase noise, consistent performance targets can be met.
- Increasing the number of symbols per TTI: In a given frequency band, it may be desirable to vary the TTI size by increasing the number of symbols per subframe. This approach may be useful in reducing control and reference signal overhead. In order to simplify scheduling of variable length TTIs, a base TTI length may be defined. A longer TTI may be configured as a multiple of the base TTI length.

An illustration of these example scenarios for a variable TTI is provided in Figure 2.

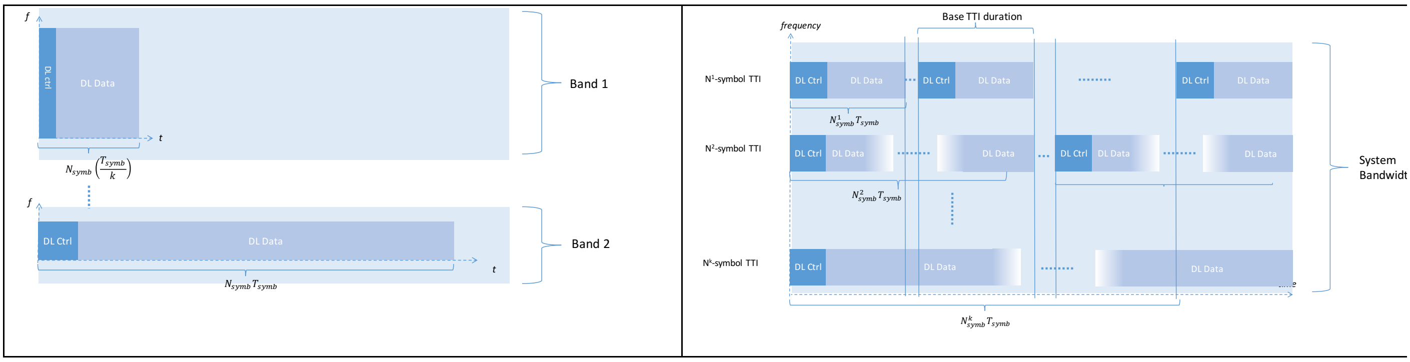

Figure 2. Options for variable TTI length. Left: variable sub-carrier spacing; Right: variable number of symbols per TTI.

4. Conclusion

This document has addressed the diverse requirements feeding into the design of a NR. In particular, considerations have been given for defining the numerology and frame structure to support the diverse usage scenarios targeted for the next generation RAT. Based on these considerations we make the following proposals:

- **Proposal**: Consider a configurable frame and numerology to address the diverse next generation deployment scenarios
    - In particular, consider a configurable TTI length to meet the performance targets for all use cases

5. References

[1] TR 38.913, “Study on Scenarios and Requirements for Next Generation Access Technologies”

[2] RP-160671, “New SID Proposal: Study on New Radio Access Technology”, NTT DOCOMO

[3] TR 36.881, “Study on latency reduction techniques for LTE”

[4] R1-162929, “Overview of OTFS Waveform for Next Generation RAT”, Cohere Technologies

[5] R1-162930, “OTFS Waveform for New RAT”, Cohere Technologies