Perspectives on New Waveform Design for 5G Small Cell

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Abstract

Mobile Internet and Internet of Thing (IoT) have been widely recognized as the two major driven forces of next generation mobile systems (IMT-2020 or 5G). Key performance indicators (KPI) of 5G are identified to satisfy the needs of these applications. It is analyzed that a new waveform design with large bandwidth at high frequency for small cell is expected for some critical KPIs. In this paper, perspectives on new waveform design for 5G small cell are presented. Specifically, the design principles for transmission time interval (TTI), system bandwidth, the subcarrier spacing, the cyclic prefix (CP), guard period (GP) and frame structure are discussed. The feasible range of numerology of the new waveform considering efficiency, flexibility and backward compatibility jointly is derived. Finally, an exemplary numerology for 5G small cell is given.

1. Introduction

With the global commercialization of 4G (LTE/LTE-A) network, the whole world naturally begins to look forward to the standard of next generation wireless system. Meanwhile, rapid growth of Mobile Internet and Internet of Thing has foreseen extreme high performance requirements, in terms of orders of system capacity and number of connection increase, of wireless network which is believed to be out of the capability of current standards, and should be fulfilled by a new standard. As it is expected to be launched in year 2020, the next generation wireless standard is entitled as IMT-2020 by ITU, whereas it is inherently called as 5G in wireless community. The research on scenario, requirements and key technologies of 5G has been carried out for a little while within government sponsored projects, industry alliances and leading companies [1], such as 5GNOW[2], METIS [3], 5GIC [4], and China IMT-2020 WG[5].

Even though it is still not boldly confirmed by all, the KPIs of 5G proposed within aforementioned R&D bodies [3][5] represent voices of most state-holders in our community. It is analyzed that 5G should outperform 4G from following five KPIs: 1) Capacity: increased by 1000x; 2) Peak data rate: increased by 10x, to be 10Gbps; 3) Latency: reduced by 10x, to be 1ms; 4) Number of connection: increased by 100x-1000x; 5) Energy efficiency: increased by 100x-1000x. Different technologies have been explored to meet the requirements. This paper focus on first three that are traditionally more visible to end-user experience.

As one of three basic elements, new spectrum resources should be explored to increase the capacity/peak rate. It is forecasted that additional 1000MHz is required till year 2020. In first stage, the potential available spectrum resources between 3GHz and 6.5GHz, as stated in Table I, are now under investigating and will be released in WRC-15. Further exploration of spectrum above 6.5GHz will be carried out then after and decided in WRC-18. The identified new spectrum resource will be most probably used in small cell due to both its propagation property and network densification trend driven by capacity increase.

Table I WRC-15 Ongoing research frequency spectrum for 5G

Frequency Spectrum	Available Frequency Spectrum
3600-3800MHz	3600-3700MHz (100MHz)
4400-4500MHz	4400-4500MHz (100MHz)
4500-4800MHz	4500-4800MHz (300MHz)
4800-4990MHz	4800-4990MHz (190MHz)
5350-5470MHz	5350-5470MHz (120MHz)
5850-5925MHz	5850-5925MHz (75MHz)
Above 6GHz	5925-6425MHz (500MHz)

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Reuse the air interface design of LTE in new spectrum is straight forward, however, not optimal in certain aspects: 1). High bandwidth in new spectrum with narrow subcarrier width of LTE will introduce larger FFT size which resultants larger PAPR; 2). Sub-ms latency cannot be achieved with 1ms sub-frame design of LTE; 3). The propagation property of new spectrum within small cell is quite different; etc. As a consequence, a new waveform design including TTI, system bandwidth, subcarrier spacing, CP length, guard period, and frame structure should be investigated for high frequency band for 5G small cell. This paper derives the feasible range of numerology of new waveform design considering efficiency, flexibility and backward compatibility jointly, followed by a typical exemplary numerology.

2. New Waveform Design

To simplify our analysis, we assume that the new waveform is an OFDM system. Please be aware that new waveform based on other multi-carrier technologies such as GMC, FMBC could be straight forward with our method, however, with a variation of set of elements. Before going into detail, a set of parameters/requirements of small cell implied or derived by 5G KPIs are shown in Table II, based on which the feasible range of TTI, subcarrier spacing, CP, guard period and frame structure are discussed

Table II Parameters/requirements for 5G small cell with high frequency

Requirement	**Value**
Carrier Frequency	3~6.5GHz
bandwidth	>=100MHz
Coverage radius	50m
Peak data rate	10Gbps
Latency	1ms

Generally speaking, there could be large number of numerologies of new waveform to achieve the performance requirements, e.g. 10Gbps peak data rate and 1ms latency, with available resources, e.g. large bandwidth between 3GHz and 6.5GHz. If it is true, there could be big challenge to search for the optimal design over a large space. Our following analysis shows that the feasible range of numerology of the new waveform considering efficiency, flexibility and backward compatibility jointly is in fact quite limited.

1) TTI

One of the challenges that arise from new applications, such as virtual reality or real-time remote services, is the very low latency. The LTE U-plane latency analysis for reference, is illustrated as Table III [8].It can be seen that the U-plane latency consists of three parts: processing delay (UE, eNB, UPE), delay associated with TTI (3*TTI) and Ts1u. Supposing the processing capability for 2020 era will be improved by 10x, then the total U-plane latency will be 2.5ms/10+3*TTI+Ts1u. Not considering Ts1u, to reduce the U-plane latency to be 1ms, TTI should be less than or equal to 0.25ms. From the perspective of compatibility, TTI for 5G small cell should be divisible by 1ms. The shortest TTI for LTE is 1ms. Thus, the candidate TTIs can be listed as 0.1ms, 0.125ms, 0.2ms, 0.25ms. Apart from the latency, another advantage for short TTI is that much flexibility can be provided in some fields, such as DL/UL resource configuration, and dynamically power on/off.

Table III U-plane latency analysis (estimated average) - TTI = 1 ms

Step	Description	Value
0	UE wakeup time	Implementation dependent - Note included
1	UE Processing Delay	1ms
2	Frame Alignment	0.5ms (TTI/2)
3	TTI for UL DATA PACKET (Piggy back scheduling information)	1ms (TTI)
4	HARQ Retransmission (30%)	0.3*5*1ms (Probability*HARQ*TTI)
5	eNB Processing Delay (Uu → S1-U)	1ms
6	S1-U Transfer delay	Ts1u (1ms - 15ms)
7	UPE Processing delay	0.5ms
	Total one way delay	5.5ms + Ts1u

2) System Bandwidth

Generally, high modulation order modulation, MIMO and large bandwidth are the ways to improve link level data rate. To achieve certain data rate, there might be a trade-off between utilized spectrum and spatial streams. For example, 10Gbps could be achieved with 100MHz, plus 64QAM with 2/3 coding rate, plus 32 MIMO, or 500MHz, plus 64QAM with 2/3 coding rate, plus 8 MIMO. Noting that the propagation of high frequency signal is with weak scattering, the number of MIMO streams could be limited. Thus, system bandwidth up to 500MHz is preferred in high frequency band to achieve 10Gbps peak data rate. Similar to LTE, the air interface design for 500MHz can be scaled down to 300MHz, 250MHz, etc.

3) Subcarrier Spacing

The subcarrier spacing for 5G small cell should be increased compared with LTE (15KHz) due to several factors. First of all, the large system bandwidth with narrow subcarrier width may introduce large FFT size which further introduces large Peak-to-Average Power Ratio (PAPR) issues. A 500MHz system with 15KHz subcarrier will be with ~50dB PAPR. On the other hand, subcarrier spacing design should consider the ability against Doppler frequency shift and system efficiency. Larger subcarrier spacing without losing much efficiency is preferred. Finally, from the point of implementation, the compatibility should be considered. The subcarrier spacing for 5G would better to be 2 of integer power of 15 KHz, such as 30 KHz, 60 KHz, 120 KHz, and 240 KHz and so on.

4) Cyclic prefix

To reduce the ISI (inter symbol interference) caused by the multi-path, CP should be designed longer than the maximum multiple path delay. It is worth noting that small cell with high frequency has the similar coverage and frequency point as WLAN. According to [9], the typical multiple path delay is 0.73us and the root-mean-square delay is 100ns. So the CP duration should be larger than 0.73us.

5) Guard period

It's known that GP (Guard Period) is used to support the switch from DL to UL. Typically, GP should be calculated as $GP = \frac{2 \times r}{3 \times 10^8} + T_{RX\text{-}TX}$, where r denotes the coverage radius.

6) Frame Structure

Compatibility should be paid much attention to for frame structure design. This is because that for the future multiple layer coverage networks, especially control/user plane splitting configuration, small cell should co-work well with macro cell configured with LTE. Thus, the frame design of small cell should align with LTE in time domain. One recommended frame structure is shown as Fig.1, which retains the frame and subframe length of LTE, however, with multiple mini-slot per subframe.

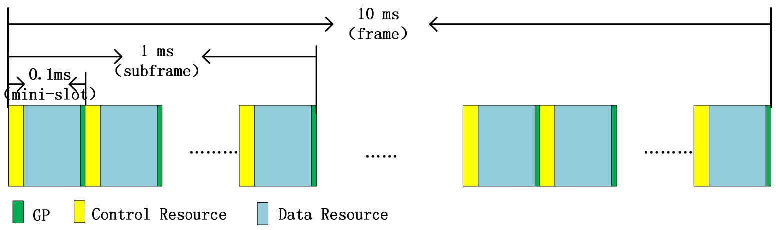

Fig 1 Frame structure

The resource allocation cycle in small cell is one sub-frame. In order to support flexible DL/UL resource allocation within one subframe, the special subframe design (adopting guard interval) in LTE for DL/UL switch is given up. Instead, each mini-slot is composed of one Guard Period, one control part and one payload part. Fortunately, GP duration for small cell is very short due to its small coverage range. If the coverage radius is 50m, then GP is approximate to 0.33us.

3 Exemplary Numerology

Considering the above design principles, we can quickly come up with an exemplary frame structure design with detailed parameters is provided in Table IV, where the subcarrier with 240 KHz is assumed. The final optimization of the subcarrier spacing will be obtained based on the channel measurement of targeting spectrum.

Table IV Frame Parameters for new frame structure

System bandwidth	100MHz, 125MHz, 175MHz, 250MHz, 300MHz, 500MHz
Subcarrier spacing	240kHz
Symbol duration	4.17us
CP duration	0.79us
GP duration	0.88us
# Symbol per mini-slot	20
# Mini-slot per subframe	10
Mini-slot duration	0.1ms
Subframe duration	1 ms
# Subframe per frame	10
Frame duration	10ms

4. Conclusion

New waveform should be designed for small cell to fulfill the performance requirements of 5G. By considering efficiency, flexibility and backward compatibility jointly, the feasible range of numerology of the new waveform including transmission time interval (TTI), system bandwidth, the subcarrier spacing, the cyclic prefix (CP), guard period and frame structure is derived. A typical exemplary numerology is given in the end as the framework for performance evaluation of other key technologies in our future R&D work.

5. Acknowledge

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6. References

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