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A Flexible 5G Frame Structure Design for Frequency-Division Duplex Cases

Klaus I. Pedersen, Gilberto Berardinelli, Frank Frederiksen, Preben Mogensen, and Agnieszka Szufarska

ABSTRACT

A 5G frame structure designed for efficient support of users with highly diverse service requirements is proposed. It includes support for mobile broadband data, mission-critical communication, and massive machine communication. The solution encompasses flexible multiplexing of users on a shared channel with dynamic adjustment of the transmission time interval in coherence with the service requirements per link. This allows optimizing the fundamental tradeoffs between spectral efficiency, latency, and reliability for each link and service flow. The frame structure is based on in-resource physical layer control signaling that follows the corresponding data transmission for each individual user. Comparison against the corresponding LTE design choices shows attractive benefits.

INTRODUCTION

Research toward a new fifth generation (5G) air interface is currently ongoing in both academia and industry. This includes defining 5G requirements and identifying candidate techniques to be included in a future system design. Despite the relatively short time of 5G research, the open literature includes an impressive number of 5G related studies; hence, we only provide pointers to some of those in the following. Among others, the METIS project has outlined its 5G vision in [1], the 5GNOW project presented their proposal for asynchronous access and related waveform designs in [2], while the use of more advanced centralized network architectures for 5G was suggested in [3]. Furthermore, small cell optimized design has been identified as being of particular importance to be able to meet the future mobile broadband traffic requirements [4, 5]. There is consensus on the fact that 5G should push the performance limits significantly further toward having virtually zero latency and multi-gigabit-rate end-user experience, and efficient machine-type communication (MTC), depending on the application requirements [6, 7]. For fulfilling such diverse (and sometimes conflicting) requirements, our hypothesis is that a highly flexible and configurable air interface is needed. In that context, the radio frame structure, and especially the methods for multiplexing (mux) of users, are some of the key design choices.

Our focus is therefore on presenting a flexible frame structure capable of fulfilling the challenging 5G requirements for efficient support of a mixture of diverse services. We start by identifying the main requirements and spectrum availability. Although we strive toward having an agnostic solution that is carrier-frequency-independent, we primarily focus on use cases for below 6 GHz for early 5G deployments around 2020. This is motivated by the fact that spectrum regulators will discuss band allocations for mobile communications above 6 GHz no sooner than 2019. The derived flexible frame structure is presented for the frequency-division duplex (FDD) use case applicable for macrocell deployments. However, several merits of the suggested solution are equally applicable for time-division duplex (TDD) bands. An air interface with orthogonal frequency-division multiple access (OFDMA) is assumed, where users are scheduled on a time-frequency grid of resources [8]. However, the proposed frame structure is also applicable for other candidate waveforms that offer a time-frequency symbol space for a commonly shared channel per cell. The corresponding relationship between physical (PHY) layer control and data channels is outlined, and numerical results are presented. Throughout the article, the Long Term Evolution (LTE) 4G standard [9, 10] is used as our reference for motivating and quantifying the benefits of the new 5G frame structure.

REQUIREMENTS AND SPECTRUM

AIR INTERFACE REQUIREMENTS

The International Telecommunication Union (ITU) has recently defined challenging requirements for international mobile telecommunications (IMT) in 2020 and beyond [6]. Among others, peak data rates of even up to 20 Gb/s and uniform availability of end-user-experienced data rates of 100 Mb/s to 1 Gb/s are listed. Support for mobile broadband (MBB) requires relatively large bandwidth and frequent transmissions. In addition to offering connectivity for humans, 5G should also be designed for efficient MTC. MTC use cases include massive machine communication (MMC) with a large number of connected

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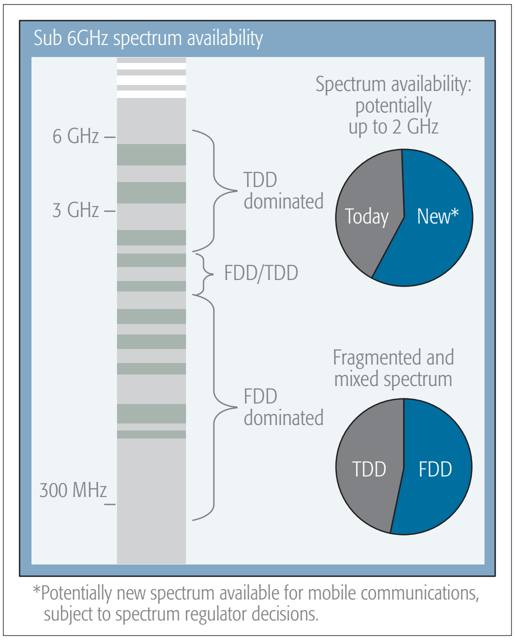
High contiguous carrier bandwidths of 100–200 MHz are especially relevant for the 3–6 GHz spectrum range, while carrier bandwidths of up to 40–100 MHz for sub-3-GHz FDD deployments are likely adequate in combination with efficient spectrum aggregation techniques.

low-cost devices (e.g., sensors). MMC is characterized by infrequent access, typically transmitting only moderate size payloads with relaxed latency requirements. Devices for MMC are typically associated with requirements for extremely low energy consumption and low cost, meaning that it is desirable to have such devices operate with relatively low radio bandwidth transmission and reception leading to lower transceiver complexity. The second class of MTC use cases is mission-critical communication (MCC). MCC requires lower end-to-end latency and a high degree of reliability to, for example, support vehicular use cases and factory automation processes. In this context, ITU has set a target to achieve a 1 ms over-the-air communication round-trip time (RTT) for a single transmission. This includes transmission of the payload until the corresponding acknowledgment (Ack) is received. Depending on the application, reliability constraints of up to six-sigma (99.99964 percent) are mentioned [1]. For more information on 5G requirements, also see [7].

Designing a system that supports all of the MBB, MMC, and MCC targets is rather challenging, especially since there are fundamental trade-offs in wireless systems between offering high spectral efficiency, low latency, and high reliability [11]. As an example, the performance of MBB can approach the Shannon capacity limit, while there is a cost of reduced spectral efficiency if operating under strict latency and reliability constraints. Our hypothesis is therefore that this calls for a flexible air interface design that allows optimizing each link according to its service requirements. This suggests having a dynamic frame structure that offers the possibility to perform trade-offs between spectral efficiency, energy efficiency, latency, and reliability in coherence with the requirements per link.

Spectrum Availability

Nowadays, the allocated spectrum for mobile communication is all below 6 GHz, and the 2015 World Radiocommunication Conference (WRC) will focus on further sub-6-GHz band allocations. WRC 2019 is expected to also consider band allocations above 6 GHz (e.g., for future 5G deployments). This essentially means that the first commercial 5G deployments around 2020 will need to focus on frequencies below 6 GHz due to regulatory band constraints for mobile communications. As illustrated in Fig. 1, the spectrum below 6 GHz is rather fragmented and composed of a mixture of bands for operating with FDD and TDD, also referred to as paired and unpaired bands, respectively. Depending on the region, potentially up to 2 GHz of spectrum is available below 6 GHz for future mobile radio communication, with nearly equal availability of bands for FDD and TDD deployments. It is especially worth noting that less than half of the potentially available spectrum for mobile communications below 6 GHz is used today. Bands for FDD are primarily available below 3 GHz, although some FDD bands are also available at higher frequencies. The efficient utilization of the spectrum below 6 GHz calls for supporting different carrier bandwidths and flexible spectrum aggregation techniques. In LTE, spectrum aggregation is supported in the form of carrier aggregation (i.e., cell aggregation) [12], while one enhancement under study for 5G is support for aggregating fragmented spectrum to form one logical cell. High contiguous carrier bandwidths of 100–200 MHz are especially relevant for the 3–6 GHz spectrum range, while carrier bandwidths of up to 40–100 MHz for the sub-3-GHz FDD deployments are likely adequate in combination with efficient spectrum aggregation techniques.



*Potentially new spectrum available for mobile communications, subject to spectrum regulator decisions.

Figure 1. Overview of spectrum availability below 6 GHz.

In this study, our focus is on the design of a flexible spectrum-agnostic frame structure for the spectrum below 6 GHz, with emphasis on solutions for licensed FDD (paired) deployments. The lower FDD bands are especially attractive for providing wide area coverage and outdoor-to-indoor coverage due to the more favorable radio propagation conditions compared to using higher frequency bands. Specifics related to frame design for unlicensed small cell TDD operating below 6 GHz are outside the scope of this study.

Flexible Frame Structure

Time-Frequency Multiplexing of Users

The ability to efficiently adapt and optimize the radio resources for each user in coherence with its service requirements is desirable. Among other things, this requires a highly flexible frame structure. The basic concept is illustrated with the time-frequency grid depicted in Fig. 2a, where a number of users are flexibly multiplexed over the available resources with different transmission time interval (TTI) durations. Each tile refers to the smallest allocation unit of time duration Δt and frequency size Δf. In practice, Δt would equal an integer number of orthogonal frequency-division multiplexing (OFDM) symbols, while Δf corresponds to an integer number of subcarriers. Those values could equal just a few symbols and/or subcarriers. The value of Δt determines the minimum TTI size for scheduling a user,

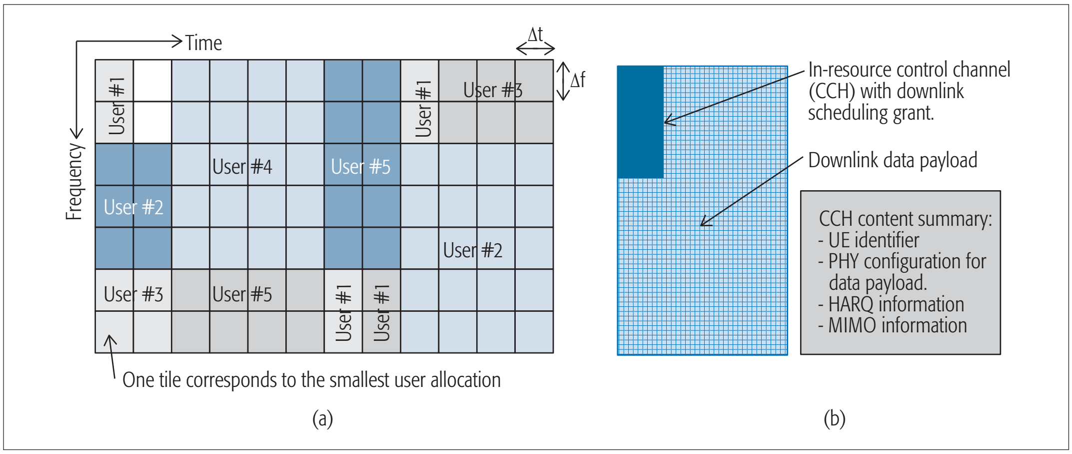


Figure 2. Dynamic time-frequency multiplexing of users and related scheduling grants: a) time-frequency multiplexing of users; b) in-resource control signaling.

LTE features a strict periodic time-division separation of the PHY control and data, by sending the control information in the first set of OFDM symbols. For example, the physical downlink control channel is transmitted over the full system bandwidth in the first OFDM symbols of the TTI having a fixed duration of 1 ms.

as well as the resolution for other TTI scheduling options. Given the most stringent latency requirement of 1 ms for MCC, there is consensus in the research community that a minimum TTI size of no more than 0.2–0.25 ms is needed. The reduced TTI size, combined with stricter network and device processing requirements, allows a sufficient delay budget for sending the payload, receiving and processing it, followed by sending the corresponding Ack. As an example, the 5G small cell concept presented in [4] proposes Δt = 0.25 ms.

The frame structure allows the TTI size for each scheduling instant of the users to be dynamically adjusted. Thus, some users can be scheduled with a short TTI size of Δt to fulfill the RTT requirement for MCC. However, scheduling all users with this short TTI is not optimal. Using long TTIs allows us to benefit from larger coding gains to approach the Shannon capacity limit, and it also imposes lower control overhead. This comes, however, at the expense of latency increase; in that respect, the usage of longer TTIs is more beneficial for MBB users for which the required data rate may be high, and the latency requirements are less stringent. Setting the TTI size per scheduling grant furthermore offers the possibility to optimize the MBB services using TCP. During the initial data transmission session, the end-user-experienced performance is primarily determined by the RTT due to the slow start TCP procedure (i.e., TCP flow control). Therefore, it would be advantageous to first perform scheduling of the MBB TCP users with short TTIs, followed by longer TTI sizes when reaching steady state operation. In addition to the time-domain scheduling flexibility, the frame structure also allows dynamic frequency-domain scheduling, where users are served on different parts of the carrier bandwidth. This includes scheduling users on non-consecutive frequency blocks to benefit from frequency domain scheduling diversity, as known from LTE. Moreover, scheduling of low-cost MTC devices with reduced bandwidth capabilities on a small portion of the carrier bandwidth is supported as well. The MTC devices served within a narrow bandwidth can be scheduled with a longer TTI size to gain from time diversity, that is, to compensate for the lack of frequency diversity.

In the uplink direction, the flexibility to schedule users with different TTI sizes offers further advantages. While users with moderate path loss toward their serving base station are schedulable on a larger bandwidth with short TTI sizes, coverage-challenged UEs need to be scheduled with longer TTIs on a narrow bandwidth to have a sufficiently high received energy (and power spectral density) at the base station. The latter is, for example, the case for deep indoor users that experience high indoor-to-outdoor penetration loss. Restricting the uplink scheduling to always have short TTI size would therefore have a cost in terms of reduced uplink data coverage.

IN-RESOURCE CONTROL SIGNALING

In-resource physical layer control signaling for sending the scheduling grant pointing to the users' data transmission allocation is proposed. The main idea is to use embedded on-the-fly information to the users on its allocated time-frequency resources, as well as the additional information needed to decode the data. This is referred to as the users scheduling grant sent on a dedicated PHY control channel (CCH). The scheduling grant also contains information such as the allocated time-frequency resources for the users (number of consecutive time symbols per TTI, subcarrier allocation), the modulation and coding scheme (MCS), hybrid automatic repeat request (HARQ) information, and multi-antenna transmission information (e.g., number of spatial streams). The in-resource CCH is mapped at the start of the resource allocation for the user in the first time symbol(s) and over a limited part of the frequency resources, as shown in Fig. 2b. Note that the flexible allocation of in-resource CCH differs significantly from the solutions adopted in the current LTE standard. LTE features a strict periodic time-division separation of the physical layer control and data, by sending the control information in the first set of OFDM symbols [7, 13]. For example, the physical downlink CCH (PDCCH) is transmitted over the full system bandwidth in the first OFDM symbols of the TTI having a fixed duration of 1 ms.

Each uplink data transmission needs an

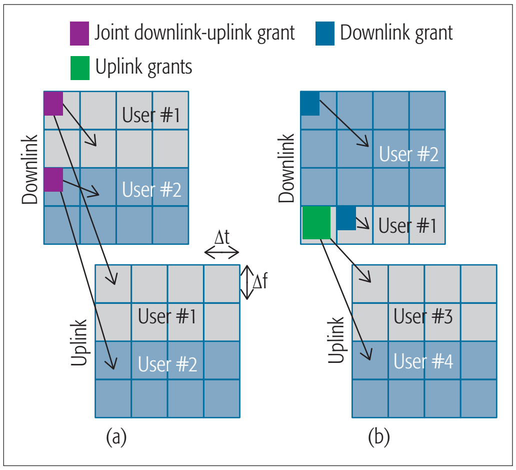
It is naturally desirable to gain from using beamforming for both PHY CCH and data channels. This is possible due to the in-resource position of the CCH, which allows using beamforming for both the CCH and the corresponding downlink data transmission in case of single stream transmission.

uplink scheduling grant that is sent in the downlink. In that respect, we opt for an uplink grant solution as illustrated in Fig. 3. In Fig. 3a, joint downlink and uplink grants are multiplexed on the same control resources dedicated to a specific user (illustrated by the purple scheduling grant), with the fundamental difference that the downlink part provides information for decoding the associated data block, while the uplink part points to a successive uplink data transmission allocation. If downlink data transmission does not occur for the user, the uplink grant can be transmitted independently, as shown in Fig. 3b (green scheduling), where multiple uplink scheduling grants are stacked in one downlink resource unit; that is, scheduling users #3 and #4 in the uplink, while scheduling users #1 and #2 in the downlink (dark blue scheduling grants).

In the interest of UE complexity and power consumption, it should be possible for the network to configure each UE with a tile pattern for monitoring the downlink CCH scheduling grants. This allows configuring low-cost MTC UEs with low data rate requirements to only monitor the downlink CCH transmissions on a narrow bandwidth of Δf and at a sparse time resolution. On a similar note, UEs with MCC can be configured to monitor for CCH transmissions on a larger bandwidth every Δt to fulfill stricter latency and reliability requirements. Finally, MBB users could be configured to for example, monitor only every nth and mth tile in the time and frequency domain, respectively. The configuration of each UE with a tile pattern for monitoring downlink CCH scheduling grants corresponds to a flexible time-frequency domain discontinuous reception (DRX) mechanism. The time-frequency domain DRX mechanism offers the possibility to control the trade-off between scheduling flexibility and UE power consumption for each link. The DRX configuration of the users is assumed to happen via higher-layer signaling, asynchronously among users, and primarily configured at connection setup. Note that LTE only supports the configuration of time-domain DRX patterns as the CCH carrying the scheduling grants is transmitted on the full carrier bandwidth.

HYBRID AUTOMATIC REPEAT REQUEST

HARQ is assumed to be an essential technique for 5G. In order to allow a high degree of scheduling flexibility, asynchronous and adaptive HARQ is assumed for both the downlink and uplink. This is in contradiction with LTE, where a synchronous HARQ solution is selected for the uplink, reducing signaling overhead, but also reducing the time-wise scheduling flexibility and implying rigid timing requirements at the same time. It is therefore proposed to have the timing for sending Acks and negative Ack (Nacks) configurable per link, as well as the number of parallel stop-and-wait (SAW) channels. The latter not only offers increased scheduling flexibility, but also more degrees of freedom for network implementations. The latter is of particular relevance for cases where the PHY and medium access control (MAC) hosting the HARQ functionality are separated on different hardware units with inter-communication delays. This is important, for instance, for supporting centralized radio network implementations with different fronthaul latencies.



(a) (b)

Figure 3. In-resource control channel design for a) joint uplink and downlink scheduling; b) separate uplink and downlink scheduling.

BEAMFORMING AND INTERFERENCE COORDINATION

Beamforming and massive multi-antenna techniques are important techniques for improving the performance of 5G. In this context, it is naturally desirable to gain from using beamforming for both PHY CCH and data channels. This is possible due to the in-resource position of the CCH, which allows using beamforming for both the CCH and the corresponding downlink data transmission in case of single-stream transmission. The former is a consequence of being able to use the same set of dedicated reference symbols for channel estimation (and coherent demodulation) for those PHY channels. This is a clear advantage over LTE, where the PDCCH is transmitted with open loop transmit diversity mode, due to the time-wise disjoint position of the CCH (PDCCH) and data (physical downlink shared channel — PDSCH). Common reference symbols (CRS) are used for both PDCCH and PDSCH transmissions [9]. In LTE-Advanced (LTE-A) there is support for dedicated reference symbols for the PDSCH demodulation when using Transmission Mode 9, while the PDCCH is still relying on common reference symbols. Additionally, with LTE-A, there is partial support for beamforming on the CCH through the enhanced PDCCH (E-PDCCH), but the initial access configuration would still need to be addressed through the PDCCH. Moreover, resource configuration for the E-PDCCH happens via radio resource management (RRC) signaling to the UE.

Furthermore, inter-cell interference is also expected to be a challenge for the 5G era, calling for both the possibility to use efficient network-based inter-cell interference coordination (ICIC) techniques, as well as receiver-based interference cancellation/suppression schemes. Since the in-resource CCH signaling for the proposed frame structure follows the data allocations, it allows efficient time-frequency domain ICIC for both the CCH and data transmission in the case of synchronized base stations. As an example, if a cell mutes a certain set of its time-frequency domain resources, users scheduled on that set of time-frequency resources in neighboring cells will experience improved signal-to-interference-plus-noise ratio (SINR) for both the CCH and data reception. The same flexibility for ICIC is not possible for LTE due to the strict time division of PDCCH and data in each TTI, where the PDCCH transmission is distributed over the full cell bandwidth [10, 14].

PERFORMANCE ANALYSIS

PHYSICAL LAYER NUMEROLOGY

The PHY design shall naturally be constructed to support the proposed frame structure, offering the necessary symbol space that fits with the requirements for the minimum time-frequency allocation. The current LTE PHY design, with OFDMA waveform and 14 OFDMA symbols per 1 ms TTI [10], does not fit the desire to be able to schedule users with a minimum TTI size of 0.2–0.25 ms. Table 1 summarizes the assumed 5G numerology for further assessment of the proposed frame structure, assuming the traditional cyclic prefix (CP) OFDMA [8], although other waveforms are naturally also considered for a future 5G design. We consider options for CP duration on the order of ~2 and ~4 μs, respectively. The shorter CP of ~2 μs could be sufficient for dense urban macrocell deployments, given the typical values of excess delay spread in such environments (e.g., 1.9 μs for the ITU Urban Macrocell channel model [15]). The longer CP of ~4 μs is closer to the LTE setting, allowing more diverse deployments. The assumed 5G subcarrier spacing corresponds to the LTE subcarrier spacing multiplied by a factor of 16/15 and 32/15, respectively. Hence, the corresponding sample rate can then be synthesized with the same common clock for both LTE and 5G, which is advantageous from an implementation point of view. The larger 5G subcarrier spacing (compared to LTE) offers increased robustness to phase noise. Notice from Table 1 that the symbol capacity in terms of available resource elements (i.e., subcarrier symbols) per 1 ms and 20 MHz carrier bandwidth are identical for 5G and LTE, and hence offers a fair comparison. This is a result of also assuming 90 percent bandwidth efficiency for 5G (as is the case for LTE), meaning that the effective transmission bandwidth is 18 MHz for a 20 MHz carrier configuration. Note that the 5G case with ~2 μs CP results in a lower fast Fourier transform (FFT) size, which is of particular importance for higher carrier bandwidths of, for example, 40 or 100 MHz. As the research on waveform selection and PHY numerology is ongoing, the settings in Table 1 should only be considered as an example used in this study for further assessment of the proposed frame structure.

	5G assumptions		LTE specifications
Subcarrier spacing	32 kHz	16 kHz	15 kHz
Number of subcarriers for 20 MHz bandwidth	560	1120	1200
FFT size for 20 MHz bandwidth	1024	2048	2048
Cyclic prefix	2.0833 μs	4.1667 μs	5.21 μs[1] 4.69 μs
Cyclic prefix overhead	6.25%	6.25%	6.67%
Symbol time (including cyclic prefix)	33.33 μs	66.66 μs	71.87 μs[2] 71.35 μs
TTI size	0.2 ms	0.2 ms	1 ms
OFDM symbols per TTI	6	3	14
Resource elements per 1 ms	16,800	16,800	16,800

[1] The CP equals 5.21 μs for the 1st and 8th symbols, while it equals 4.69 μs for other symbols.

[2] The symbol time equals 71.87 μs for the 1st and 8th symbols, and 71.35 μs for other symbols.

Table 1. 5G PHY numerology (examples only) and corresponding assumptions for LTE (20 MHz carrier).

CONTROL CHANNEL OVERHEAD

As the scheduling grant control channel (CCH) for the proposed 5G frame structure will essentially carry the same information as the LTE scheduling grants on the PDCCH, we

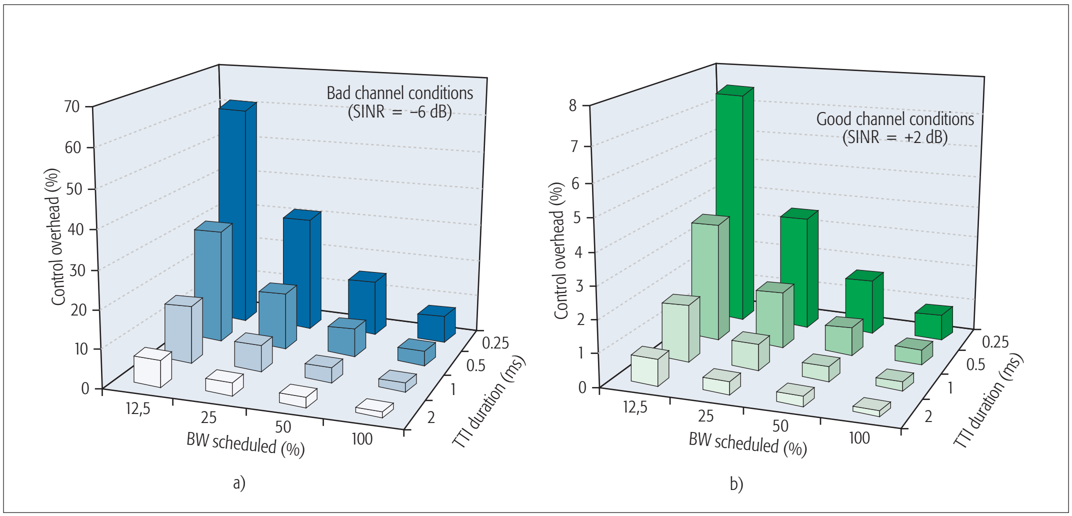


Figure 4. Control channel overhead for different time-frequency scheduling allocations and terminal experienced SINR conditions; a) CCH overhead for bad channel conditions; b) CCH overhead for good channel conditions.

	5G proposal	LTE
TTI size	Variable TTI size. Adjustable per user and per scheduling instant in steps of 0.20–0.25 ms.	Fixed 1 ms TTI size.
RTT	Below 1 ms when scheduling with a short TTI size of 0.20–0.25 ms.	8 ms.
PHY CCH and data channel mux	In-resource control signaling, where CCH and data channel transmissions are aligned, using the same bandwidth.	Strict time mux between PHY control and data. PHY control (PDCCH) is sent as wideband. Control channel blocking can occur.
DRX	Flexible time-frequency configuration of pattern for UE monitoring of downlink CCH scheduling grants.	Flexible time-domain-only configuration of pattern for UE monitoring of downlink control scheduling grants.
HARQ	Asynchronous HARQ for uplink and downlink with configurable number of parallel stop-and-wait channels supporting incremental redundancy.	Synchronous HARQ for uplink and asynchronous HARQ for downlink. Fixed number of parallel stop-and-wait channels supporting incremental redundancy.
UE bandwidth operation	UE can operate on a fraction of the carrier bandwidth – especially attractive for low-cost MTC devices.	UE needs to monitor the full carrier bandwidth up until Rel-12 as the PDCCH is transmitted on the full carrier bandwidth (MTC enhancements coming in Rel-13).
ICIC	Full support for dynamic time-frequency domain ICIC, offering protection for CCH and data channels due to the in-resource control signaling design.	Only time-domain ICIC for PHY control, and time-frequency domain ICIC for PDSCH.
Beamforming	Support for (rank-1) beamforming for both the PHY CCH and data channel due to the in-resource control design.	Open loop transmit diversity for PHY control and beamforming support for PDSCH. E-PDCCH supports beamforming,
Carrier bandwidth	5 MHz, 10 MHz, 20 MHz, 40 MHz, 100 MHz. (potentially with additional options within this range)	1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, 20 MHz.
Spectrum aggregation	Support for aggregation of fragmented spectrum to form one cell, as well as aggregation of cells.	Carrier aggregation, that is, aggregation of individual cells.

Table 2. Summary of proposed 5G characteristics vs. assumptions for LTE.

assume the same basic structure and air interface decoding performance. The PDCCH for a user in good SINR conditions can be sent with quadrature phase shift keying (QPSK) and coding rate 7/10 on a total of 36 resource elements (REs). Such a configuration results in an average reception block error rate (BLER) of less than 1 percent if the post-detection SINR is at or above 2 dB. On the other extreme, the PDCCH could also be sent with QPSK rate 1/11, which in turn would be able to provide the needed 1 percent BLER for users in challenging SINR conditions of down to –6 dB. This requires a total of 288 REs. Notice that for the 3GPP defined macro scenarios, less than 1 percent of the users have a post-detection SINR of –6 dB (assuming standard 2 × 2 single-user open loop transmission diversity). More details on the LTE PDCCH performance can be found in [10, 14]. In addition to the CCH overhead, it is assumed that 10 percent of the REs are used for reference symbols to facilitate channel estimation and coherent demodulation.

Given these assumptions for the required number of REs for the CCH, the relative control overhead for the proposed 5G frame structure is calculated. The relative control overhead is defined as the ratio of used REs for the CCH overhead vs. the total number of used REs for data, control, and reference symbols. The results in Fig. 4 show how the CCH varies depending on the relative scheduling bandwidth and TTI duration. The example in Fig. 4 assumes a 20 MHz carrier bandwidth. It is observed that the CCH overhead scales linearly with the scheduling of users due to the in-resource CCH signaling. For instance, if a low-bandwidth user in poor channel conditions is scheduled with very low latency (short TTI size), the associated overhead of the scheduling equals 61 percent, while scheduling a user in good channel conditions with larger bandwidth and longer TTI size will result in a much lower overhead of less than 1 percent. It should be noted that the CCH overhead values experienced with the proposed 5G frame structure will be between these two extreme values, and will be a result of the traffic in the network and the applied scheduling policy. Thus, trade-offs between CCH overhead and TTI size, or equivalently RTT, are allowed. The fact that the CCH overhead is not hard limited to values of 7, 14, and 21 percent, as in LTE, presents a more flexible solution, where CCH blocking is further reduced; see results on LTE PDCCH blocking in [14] with realistic QoS-aware scheduling.

Key Characteristics vs. LTE

The key characteristics of the proposed 5G frame structure are summarized in Table 2, including comparison against the corresponding design choices for LTE Release 12 (Rel-12). Table 2 shows attractive benefits of the proposed 5G solution, which essentially map to increased flexibility for efficient multiplexing of users with extremely diverse service requirements on the same air interface. Among other characteristics, the proposed design offers shorter RTT when needed, the flexibility to optimize for high throughput at the expense of latency, as well as efficient MTC support for each link.

CONCLUSION

A flexible 5G FDD frame structure is presented for multiplexing users with highly diverse service requirements and radio conditions. This allows us to optimize the resource allocation on a per link basis. The concept is based on in-resource physical layer control signaling that follows the corresponding data transmission for each individual user. The proposed design offers a short air interface round-trip time when needed, the flexibility to optimize for high throughput at the expense of latency, as well as efficient machine-type communication support. Given these merits, it is suggested to continue the work on such a frame structure. As an example, it remains to be studied how to arrange downlink common channels like system broadcast information, as well as how to most efficiently facilitate multiplexing of uplink control information including HARQ feedback, channel state information, and so on. Similarly, adaptation of the frame structure to TDD cases is another topic of interest.

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