5G enabling technologies

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Topics

- Massive MIMO Communications
- Millimeter-Wave Mobile Communications
- Non-Orthogonal Multiple Access (NOMA) for Future Radio Access
- New Multicarrier Modulations for 5G
- Generalized Frequency Division Multiplexing: A Flexible Multi-Carrier Waveform for 5G
- Spectrally Efficient Frequency Division Multiplexing for 5G
- Full-Duplex Wireless Communications for 5G
- Device-to-Device Communications over 5G Systems
- Conclusions
Enabling Technologies

- To provide specifics to support the application requirements, 5G enabling technologies are necessary for an ultra broadband network.
- Envisaged technologies:
  - MIMO, new radio waveforms
  - Advanced cancellation interference techniques (e.g. ICIC, CoMP)
  - Techniques to improve the throughput (e.g. carrier aggregation, dual connectivity, simultaneous Tx-Rx)
  - Small cells, ultra dense network, cloud RAN, Device-to-Device
  - Specific radio interface/architecture (from LTE-A) such as massive Machine Type Communications (mMTC) and public safety communications
Multiple Input Multiple Output (MIMO)

- Area throughput \([\text{bit/s/km}^2]\) = Bandwidth [Hz]  Cell density [cells/km\(^2\)]
  - Spectral efficiency \([\text{bit/s/Hz/cell}]\)
    - In previous network generations have greatly resulted from cell densification (see urban environment) and allocation of more bandwidth
    - MIMO improves the Spectral Efficiency of future networks
- Single Input Single Output capacity is according to Shannon formula (not efficient)
- In the cellular system, Shannon capacity is multiplied by \(N_{BS}\).
- MIMO strategies:
  - Single point-to-point MIMO
  - Multi-User MIMO

**SU-MIMO**

**MU-MIMO**
MIMO: basic principle

- $N_t$ tx antennas, quasi-static channel (i.e. $T_b \ll T_{coh}$), $N_r$ rx antennas
- $H$ is the $N_r \times N_t$ channel matrix with whose entries $h_{ij}$ are complex channel gains (transfer functions) from the $j$-th transmit to the $i$-th receive antenna.
- The received signal vector: $r = Hs + n = x + n$ contains the signals received by $N_r$ antenna elements, where $s$ is the transmit signal vector and $n$ is the noise vector.
- Consider a singular value decomposition of the channel: $H = WA^\dagger$, where $\Lambda$ is a diagonal matrix containing singular values, and $W$ and $A^\dagger$ are unitary matrices composed of the left and right singular vectors, respectively.
- The received signal is: $r = Hs + n = WA^\dagger s + n$
- Multiplication of the transmit data vector by matrix $U$ and the received signal vector by $W^\dagger$ diagonalizes the channel: $W^\dagger r = W^\dagger WA^\dagger Us + W^\dagger n'$; $r' = \Lambda s + n'$
- $R_H$ (rank of matrix $H$) parallel channels (eigenmodes of the channel) $\rightarrow$ the capacity of parallel channels just adds up.

$$(.)^\dagger = ((.)^T)^*$$
Massive MIMO Communications

- Spatial multiplexing
  - High-rate signal is split into multiple lower-rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel

- Diversity
  - Selecting the best signal among the received ones

- Beamforming
  - Single stream with a given phase, depending on the position of the reference user

- Massive MIMO is when the number of antennas are much greater than the sum of the antennas of the receiving users: $M \gg K$
  - For Multi-User MIMO, the channel response for two users (i.e., $h_1, h_2$) becomes asymptotical orthogonal: \( h_1 \cdot h_2 / M \to 0 \) (BS can completely separate users’ signals)
  - TDD to save pilot signals
  - **Challenges**: pilot contamination in a multi-cell scenario, users have similar paths (low scattering), pilot standardization
Millimeter-Wave Mobile Communications (mmWave)

- Complementary to the low frequency band → coexistence of low frequency and high frequency communication (hybrid network)
  - The conventional LTE is responsible for seamless coverage due to its longer range
  - The mmWave communications are served as multiple hotspots scattered in the cell.
- Advantages:
  - Potential availability of large amount of spectrum
  - Large continuous spectrum chunks.
- Frequency and Channel propagation issues:
  - Higher pathloss, high rain attenuation
  - Reduced diffraction, higher attenuation from outdoor-to-indoor (e.g. walls)
  - Smaller antenna size, use of beamforming
- Candidate frequencies: 6 GHz, 15 GHz (group 6-20 GHz), 28 GHz, 38GHz (group 20-50 GHz), 60 GHz, and E-band (71–76GHz, 81–86GHz) (group 50-100 GHz).
mmWave

- Use of mmWave for a unified access and backhaul (UAB) network
  - Radio Access for small cells and hotspots
  - Back-Hauling (narrow beam)
- The UAB network utilizes a C/U split configuration
  - The control-plane (C-plane) is managed by macro base stations (MBs) through low frequency bands
  - The user plane (U-plane) uses a mmWave base stations (mBs) through high frequency bands.
- Backhaul link from the mBs to the MBs
  - Use of mmWave, to save fiber cost deployments
  - Use of in-band backhaul (in LTE-A use of out-band Tx for relays), due to spectrum availability
- Request to have a unified air interface → reuse of radio access parameters of lower frequencies, adoption of configurable parameters for flexibility
mmWave

- Radio access and backhaul share a continuous bandwidth → Need of interference mitigation between radio access and backhaul
  - All mBs share a same resource partition ratio so as not to interfere with each other
  - The ratios can also be dynamically adapted over time.

**Dynamic Resource Allocation**
- Backhaul band \((B_{BH})\) and Radio Access Band \((B_{RA})\), \(B = B_{BH} + B_{RA}\)
- Backhaul Throughput of the \(n\)-th mBS \(T_{BHn} = R_{BH} \cdot B_{BH}\), and radio access Throughput \(T_{RAn} = R_{RAn} \cdot B_{RA} = R_{RAn} (B - B_{BH})\), with \(R_{BHn}\) and \(R_{RAn}\) are the corresponding data rates
- For any mB, its throughput \(T_n = \min[T_{BHn}, T_{RAn}]\), triangular function with \(B_{BH}\)

**Strategies:**
- Max-Min: Maximization of the minimum throughput
- Max-Sum: Maximization of the sum throughput
- Quasi-PF: Maximization of the satisfactory factor
Non-Orthogonal Multiple Access (NOMA) for Future Radio Access

- **Code Division Multiple Access (CDMA)**
  - An user is assigned a unique code sequence (spreading code) to enable multiple access \(\rightarrow\) every user increases the interference level (background noise), power control is mandatory
  - Code sequences have to be chosen very carefully: good cross-correlation to reduce the multiple access interference (MAI), good auto-correlation to reduce the inter symbol interference (ISI).

- **Large Area Synchronised CDMA**
  - Research efforts for spreading sequences, which benefit from zero correlation values for the delay-induced code offset is in the so-called zero correlation zone (ZCZ) or interference free window (IFW)
  - The resultant LAS codes exhibit an IFW, where both the off-peak aperiodic auto-correlation values and the aperiodic cross-correlation values become zero. Therefore this system has zero ISI and zero MAI, as long as the time-offset of the codes is within the IFW.
  - **Disadvantages**: limited number of IFW codes; auto-correlation and cross-correlation function higher outside the IFW
Non-Orthogonal Multiple Access (NOMA)

- **Multi-Carrier CDMA (MC-CDMA)**, a combination of OFDM and CDMA
  - Spreads each user symbol in the frequency domain
- **Advantages**: decreasing the symbol rate → simpler synchronization
- In uplink, non-orthogonal users cause multi-user interference (MUI): need of MultiUser detection → computationally complex
- Proposal of partition the available subcarriers into groups and distribute users among the groups to reduce the MUD complexity: Group Orthogonal MC-CDMA (GO-MC-CDMA)
  - The users that are assigned subcarriers of the same group are separated using spreading codes → no interference from other groups
  - Each group has a smaller number of users, making the optimum MUD computationally feasible within each group
Non-Orthogonal Multiple Access (NOMA)

- **Low Density Signature CDMA (LDS-CDMA)**
  - **Basic idea**: to switch off a large number of chips for each symbol so the signature matrix will be a sparse matrix → each user will spread its data over a small number of chips
  - Reduced processing gain AND reduced number of users at each received chip $K \ll N \rightarrow$ reduced receiver complexity
    - Further reduction in MUD using grouped-based technique
  - LDS-CDMA performance are near single-user performance even under a load of 200%
  - **Drawback**: in wideband channels, its performance degrades due to multipath fading (ISI, i.e. more users will interfere in one chip)
  - Proposal of LDS-OFDM, which introduces sparse code multiple access (SCMA) for high order modulations
New Multicarrier Modulations for 5G

- Spread use of OFDM for 4G (not selected for 3G for computational complexity). Complexity reduced with rectangular pulse, cyclic prefix and advances in amplifiers → adoption of FFT
  - In a multi-user context, need of time and frequency alignment to maintain the orthogonality

- Specific 5G requirements are asynchronous access, frequency offset compensation, coexistence issue, per-user channel equalization

- Problem of the spectral containment
  - Switching off subcarriers → not a good solution
New Multicarrier Modulations for 5G: pulse shaping

- Another solution: adopting a basic pulse whose spectral secondary lobes can be neglected.
  - Lower spectral lobes $\rightarrow$ longer time pulse $\rightarrow$ reduction in spectral efficiency
  - In OFDM add of cyclic prefix to the basic pulse, $M_{CP}+M \rightarrow (M_{CP}+M)/\rho$

- Two strategies:
  - Filter bank (abandon the time limitation) [next slides]
  - Pulse shaping (maintaining the time limitation of the pulse)

- **Pulse shaping**: rectangular pulse is replaced by
  - Hanning pulse, Raised Cosine
  - Reduction in the spectral efficiency
  - Computational complexity similar to the classic OFDM transceiver.
New Multicarrier Modulations: Filter Bank Multi Carrier

- **Filter Bank Multi Carrier (FBMC):** a low-pass prototype filter with $K M$ coefficients is shifted on the frequency axis by integer multiples of the subcarrier spacing, leading to a set of $M$ subchannels.
  - $K$ emitted multicarrier symbols overlap
  - The overlapping factor $K$ determines the filter attenuation characteristics and, thus, the spectral separation between adjacent users
  - The cyclic-prefix is not necessary $\rightarrow$ equalization to mitigate the channel distortion $\rightarrow$ no delay in the cyclic prefix
  - Receiver scheme is more complex $\rightarrow$ feasible only for low overlapping factors ($K=2, 3$)
  - Data mapping cannot be applied to FBMC, because of the filter overlapping
- The signals transmitted on the subcarriers $k + 1$ and $k - 1$ generate interference in the subcarrier $k$. Two approaches:
  - Offset-QAM modulation (i.e. FBMC-OQAM). The principle relies on the impulse responses of interference filters that cross the zero axis at multiples of the symbol period $M$, but with a shift of $M/2$ between the real part and the imaginary part. Then, full rate is obtained if the symbol rate is doubled and real and imaginary data samples alternate in the time domain and in the frequency domain;
  - Pulse amplitude modulation (i.e. FBMC-PAM). The phase shift $\pi/2$ is applied to the subcarriers of adjacent sub-channels and the transmitter input is a real sequence of data samples
New Multicarrier Modulations: Filter Bank Multi Carrier

- Transmission of purely imaginary symbol on a subcarrier and a purely real symbol on the adjacent interfering subcarrier: $iM/2$ is the misalignment
- Further transformation for FBMC-PAM (by Malvar): good spectral confinement even for $K=2$ (low delay)
New Multicarrier Modulations: Filter Bank Multi Carrier

- **FBMC-OQAM**
  - Higher spectral containment (more significant for larger $K$)
  - Greater robustness to the imperfections of the timing and Carrier Frequency Offset (CFO) estimation procedures (more significant for larger $K$)
  - Increase of the computational complexity
  - Inefficiency in short-burst transmissions

- **The FBMC-PAM**
  - Higher spectral containment and synchronization requirement
  - Smaller complexity than FBMC-OQAM
  - Marginal inefficiency in short-burst transmissions

→ in many use cases, FBMC-PAM represents a good compromise
→ only in extreme scenarios (spectrum fragmentation), FBMC-OQAM with $K=3$ (or also with $K = 4$) may become necessary.
Generalized Frequency Division Multiplexing: A Flexible Multi-Carrier Waveform for 5G

- In 5G need of:
  - Loose synchronization for IoT
  - Low latency for Tactile Internet
  - Huge throughput (or bitpipe) applications
  - High coverage and dynamic spectrum allocation for regional/rural areas
- Adoption of MIMO and multi-antennas
- Not a specific waveform useful for all scenarios but...
- ... a flexible waveform
- ... reconfigurable for any applications
- ... feasible to customize PHY such that it can be seen as a virtual service for upper layers.
Generalized Frequency Division Multiplexing (GFDM)

- A data block of $N = K \cdot M$ symbols transmitted on $K$ subcarriers and $M$ subsymbols (slots)

$$x[n] = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} d_{k,m} \exp \left( j2\pi \frac{kQ}{S} n \right)$$

$$x[n] = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} d_{k,m} \exp \left( j2\pi \frac{k v_f T}{S} n \right)$$

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R$</td>
<td>Samples per period in the filter</td>
</tr>
<tr>
<td>$T$</td>
<td>Periods in the filter</td>
</tr>
<tr>
<td>$S = RT$</td>
<td>Total number of samples in the signal</td>
</tr>
<tr>
<td>$P$</td>
<td>Subsymbol spacing in time domain</td>
</tr>
<tr>
<td>$Q$</td>
<td>Subcarrier spacing in frequency domain</td>
</tr>
<tr>
<td>$v_l = P/R$</td>
<td>Subsymbols distance factor</td>
</tr>
<tr>
<td>$v_f = Q/T$</td>
<td>Subcarriers distance factor</td>
</tr>
<tr>
<td>$K = RT/Q = R/v_l = S/Q$</td>
<td>Subcarriers per block</td>
</tr>
<tr>
<td>$M = TR/P = T/v_f = S/P$</td>
<td>Subsymbols per block</td>
</tr>
<tr>
<td>$N = KM$</td>
<td>Number of data symbols per block</td>
</tr>
</tbody>
</table>
GFDM: transmitter and receiver

\[ d_0 \rightarrow g(n)N \rightarrow \exp(j2\pi \frac{0}{K} n) \]

\[ \vdots \]

\[ d_{K-1} \rightarrow g(n-K)N \rightarrow \exp(j2\pi \frac{K-1}{K} n) \]

\[ \vdots \]

\[ d_{0,M-1} \rightarrow g((n-(M-1)K)N \rightarrow \exp(j2\pi \frac{0}{K} n) \]

\[ \vdots \]

\[ d_{K-1,M-1} \rightarrow g((n-(M-1)K)N \rightarrow \exp(j2\pi \frac{K-1}{K} n) \]

\[ N = 28, K = 4, M = 7 \]
GFDM: reduction of out-of-band (OOB) emission

- Guard-symbol GFDM (GS-GFDM). First sub-symbol erased to zero.
- With Cyclic Prefix. Suitable for avoiding the multipath but it is necessary to put the last subsymbol null
- Windowed-GFDM (W-GFDM)
  - Reduction of efficiency
  - Linear, raised-cosine (RC) filter
- Precoded WHT: walsh-hadamard (WH) matrix to combine transmitted symbols in order to provide reliable and low latency communication in frequency selective channel
- Orthogonal QAM: combination of real and imaginary symbols
GFDM: performance
GFDM: summary

- Number of subcarriers $K$ and subsymbols $M$
- Properties of the basic pulse (pulse shaping, circularity, cyclic prefix)
- GFDM is valid for multi-service and multi-user systems

<table>
<thead>
<tr>
<th>Design space</th>
<th>GFDM</th>
<th>OFDM</th>
<th>OFDM</th>
<th>SC-FDE</th>
<th>SC-FDM</th>
<th>FBMC QOAM</th>
<th>FBMC FMT</th>
<th>FBMC COQAM</th>
<th>CB-FMT</th>
<th>FTN</th>
<th>SEFDM</th>
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<tbody>
<tr>
<td># subcarriers</td>
<td>$K$</td>
<td>$K$</td>
<td>$K$</td>
<td>$K$</td>
<td>$K$</td>
<td>$K$</td>
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<td>Scaling freq.</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>$&gt;1$</td>
<td>1</td>
<td>$&gt;1$</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Scaling time</td>
<td>$v_t$</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>&lt;1</td>
<td>1</td>
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<tr>
<td>Silent subsym.</td>
<td>$M_s$</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>$M_p$</td>
<td>$M_p$</td>
<td>–</td>
<td>–</td>
<td>$M_p$</td>
<td>–</td>
</tr>
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<td>Filter imp. resp.</td>
<td>Cyclic</td>
<td>Rect</td>
<td>Rect</td>
<td>Dirichlet</td>
<td>Dirichlet</td>
<td>$\sqrt{\text{Nyquist}}$</td>
<td>$\sqrt{\text{Nyquist}}$</td>
<td>Cyclic</td>
<td>Cyclic</td>
<td>IOTA</td>
<td>Rect</td>
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<tr>
<td>Offset mod.</td>
<td>(Yes)</td>
<td>(Yes)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Cyclic prefix</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>Orthogonal</td>
<td>(Yes)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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</tr>
<tr>
<td>Application scenarios</td>
<td>All</td>
<td>Legacy syst.</td>
<td>Bitpipe</td>
<td>IoT, MTC</td>
<td>IoT, MTC</td>
<td>WRAN, bitpipe</td>
<td>WRAN</td>
<td>Tactile internet</td>
<td>Tactile internet</td>
<td>Bitpipe</td>
<td>Bitpipe</td>
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<tr>
<td>Beneficial features</td>
<td>Flex.</td>
<td>Orth.</td>
<td>Small CP overhead</td>
<td>Low PAPR</td>
<td>Low PAPR</td>
<td>Low OOB</td>
<td>Low OOB</td>
<td>No filter tail</td>
<td>No filter tail</td>
<td>Spectral eff.</td>
<td>Spectral eff.</td>
</tr>
</tbody>
</table>
Spectrally Efficient Frequency Division Multiplexing (SEFDM) for 5G

- **Aim**: optimising spectrum utilisation for higher data rates
- Contrary to OFDM, SEFDM deliberately and counterintuitively violates the orthogonality rule defined for OFDM by reducing the spacing between the sub-carriers.
  - In SEFDM the sub-carrier spacing is equal to \( \Delta f = \alpha/T \), (T symbol duration), \( \alpha < 1 \) level of bandwidth compression (\( \alpha=1 \) for OFDM)
  - Sub-carriers are closer together \( \rightarrow \) non-orthogonal
    \( \rightarrow \) self-created ICI

\[
x(t) = \sum_{l=-\infty}^{+\infty} \sum_{n=0}^{N-1} s_{l,n} e^{j2\pi n \Delta f \alpha t}
\]

**Correlation matrix**

\[
c_{m,n} = \frac{1}{Q} \sum_{k=0}^{Q-1} e^{j2\pi mk}\frac{e^{j2\pi nk} - e^{j2\pi nk\alpha}}{1 - e^{j2\pi nk\alpha}}
\]

\[
= \frac{1}{Q} \times \left\{ \begin{array}{ll}
Q & , m = n \\
\frac{1 - e^{j2\pi (m-n)}}{1 - e^{j2\pi (m-n)}} & , m \neq n
\end{array} \right.
\]
SEFDM: transceiver and demodulation/detection techniques

- 1° stage: Demodulator
- 2° stage: first Detector
- 3° stage: second Detector

Demodulation and detection techniques
**SEFDM: summary**

- SEFDM increases multiplexing gain with respect to an OFDM
  - Use of more sub-carriers in the default OFDM bandwidth
- Sub-carriers suffering from self-created ICI
  - More complex signal processing at the receiver
  - A linear increase in the number of sub-carriers results in a more than linear increase in the complexity order of both the demodulation and detection stages
- Necessity of sophisticated detection algorithms
  - Subsequently, these algorithms are optimised to make them better-suited for application in the real world
Full-Duplex Wireless Communications for 5G

- A system simultaneously transmitting and receiving signals over the same frequency band is a fullduplex (FD) system
  - Potential of doubling the capacity
  - Beneficial to high layers, such as medium access (MAC) layer
- How much should the self-interference (SI) be cancelled?
- Maximum (BS or MS) transmit powers $P_{Tx} = 24$ dBm, the noise floor $N=-100$ dBm, Tx-Rx path isolation =15dB $\Rightarrow$ SI $= P_{Tx} - \text{path isolation} - N = 109$dB i.e. cancelled SI
- The received signal is known by the receiver. Why is self-interference hard to subtract?
  - The received version is a complicated distorted function of the original clean signal along with noise
  - Three types of sophisticated cancellation techniques: 1. propagation-domain; 2. analog-circuit-domain; 3. digital-domain
Full-Duplex Wireless Communications: SI techniques

- **Propagation-domain**
  - Electromagnetically isolate (in the wireless-propagation-domain) the transmit chain from the receive chain. Proposed solutions:
    - Increasing the Tx and Rx antenna space
    - Placing absorptive shielding between them,
    - Using different polarization (it transmits only horizontally polarized signals and receives only vertically polarized signals)
    - Using directional transmit and/or receive antennas (i.e., antennas with non-uniform radiation/sensing patterns)
Full-Duplex Wireless Communications: SI techniques

- **Analog-circuit-domain**

- **Aim:** SI cancelation in the analog receive-chain circuitry before the ADC

- **Idea:** to model and predict the distortions caused by SI and compensate the received signal accordingly in the analog domain. Three schemes:
  - Processing of the self-interference signal prior the upconversion (premixer cancelers)
  - Processing of the self-interference signal after the upconversion (post-mixer cancelers)
  - A baseband analog canceler where the canceling signal is generated in baseband and the cancelation occurs in the analog baseband
Full-Duplex Wireless Communications: SI techniques

- **Digital-domain**
  - It works after the ADC quantization
  - It applies sophisticated DSP techniques
  - Advantages: reduction of circuit complexity and power consumption
  - Disadvantages: limitation in the maximum achievable cancelation
  - Usually implemented after other SI techniques
Full-Duplex Wireless Communications: scenarios

- **FD bidirectional communication**
  - Spectral efficiency is doubled

- **FD cooperative communications**
  - A source node, a relay node, and a destination node
Full-Duplex Wireless Communications: scenarios

- **FD cognitive radio networks**
  - In CRNs, the secondary (unlicensed) users (SUs) are allowed to share the licensed spectrum with the primary (licensed) users (PUs)
  - When SUs have FD capability, they can perform simultaneous sensing and Tx

- **Use of the “listen-before-talk” strategy by SU. Two problems:**
  - Tx time reduction due to sensing
  - Sensing accuracy impairment due to data transmission
Device-to-Device Communications over 5G Systems

- **Basic idea:** Devices being close to each other can activate direct links and bypass the base station (BS) or access point (AP) by either using cellular communications resources or using alternative radio technologies such as Wi-Fi.

- **Advantages:**
  - Improved spectral efficiency and radio resource utilization
  - Improved link coverage and coverage extension
  - Increasing throughput, enabling high data rate with a low delay due to the short range
  - Cellular data traffic offloading
  - Enabling energy savings
  - Allowing communications when the radio infrastructure is damaged
  - Content sharing

**Application scenarios**

- Proximity-based social networking, gaming, ...
- Advertisements for by-passers
- Public Safety
- Traffic control/safety “Intelligent Traffic System” (ITS)
Device-to-Device Communications

- Resource D2D communications management:
  - Inband: transmitting on cellular spectrum
    - Underlay inband D2D mode: spectrum resources shared between D2D and cellular communications → mitigation techniques for coexistence
    - Overlay inband D2D mode: resources are assigned to D2D communications
  - Outband: unlicensed bands such as Wi-Fi

- Challenges:
  - Device discovery procedures to detect the presence of other UEs in the neighborhood
  - Link setup strategies to properly select the spectrum for D2D communication
  - Interference avoidance mechanisms for the coexistence among D2D UEs with cellular network
  - New devices design
D2D Communications: functionalities and architecture

- D2D communications have been introduced in LTE-A in Rel.12. Two main functionalities:
  - ProSe Discovery: the process to identify a UE in proximity of another, using E-UTRAN
  - ProSe Communication: the communication between two UEs in proximity through an E-UTRAN communication path. The communication path can for example be established directly between the UEs (mode 2) or routed via local evolved-NodeB (eNB) (mode 1).
  - ProSe-enabled UE: it is a UE that supports ProSe Discovery and/or ProSe Communication.
D2D Communications: Uses Cases and Scenarios in Rel. 12

- **Restricted/Open ProSe Discovery:**
  - A ProSe-enabled UE discovers another UE in proximity only if it has previously achieved the permission (restricted). Example: a friend in a social network
  - A ProSe-enabled UE is able to discover neighbor devices without the necessity of a permission (open). Example: shop/restaurant advertisement

- **Network ProSe Discovery:** the Mobile Network Operator (MNO) verifies if a UE has the permission to discover another UE and the proximity.

- **Service Continuity Between Infrastructure and E-UTRA ProSe Communication Paths:** the operator should be able to dynamically control the proximity criteria (e.g., range, channel conditions, achievable QoS) for switching between the two communication paths.

- **ProSe-Assisted WLAN Direct Communications:** ProSe-enabled UEs with WLAN capability when they are in Wi-Fi Direct communications range

- **ProSe Application Provided by the Third-Party Application Developer:**
  - APIs provided by the operator to third-party application developers which enable the user to use a wide variety of new ProSe applications created by third-party developers.
  - Need of mechanisms to identify, authenticate and authorize the third-party application to use ProSe capability features.
D2D Communications: architecture

- Application servers (ProSe App Server)
- Applications in the UE (ProSe UEs App)
- ProSe Functions
- Seven new interfaces/reference points
D2D Communications: Application Scenarios for 5G

- **Local Service**
  - Social apps, play games, …
  - Local data transmission (spectrum efficiency)
  - Local advertising service (e.g. discounts and commercial promotions, information about movies)
  - Cellular traffic offloading AND in hotspot areas with caching
  - Media content from close terminals

- **Emergency Communications**
  - Ad hoc network can be set up based on multi-hop D2D to guarantee wireless communication between users during a natural disaster
  - Improving coverage in blind spot by terrain or buildings

- **IoT Enhancement**
  - Vehicle-to-vehicle (V2V) communication, Vehicle-to-Infrastructure (V2I) or Internet of Vehicles (IoV)
  - Low-cost terminals (typically in IoT) can access close special terminals in D2D modality instead of direct connections with BSs.
  - Smart home managed by a D2D-based access modality instead of a small cell structure.

- **Positioning aid in critical/indoor scenarios**
  - Pre-deployed terminals can detect the location of terminals to be localized, and support indoor positioning at a low cost in 5G networks.

- **Communication enhancements**
  - Paired users may directly (in D2D) exchange information about channel status, improving the multi-user MIMO, CoMP,...
  - In mmWave, use of D2D to provide LOS for high frequencies
Solutions for …

Throughput increase
- Massive MIMO (maggiore efficienza spettrale)
- mmWave (maggiore banda)
- Full Duplex (raddoppio della banda)
- GFDM (flessibilità per supportare varie forme d’onda, efficienza spettrale cioè maggiore bit rate)
- SEFDM (ottimizzazione dello spettro)

Increase of number of connected devices
- NOMA (applicabile a tipologie d’utente molto diverse, con bassa capacità di processing nel ricevitore, con bassi requisiti di sincronizzazione)
- FBMC (spettro molto confinato –> uso di parti di spettro non assegnabili se si usasse l’OFDM; non serve una sincronizzazione estrema tra gli utenti –> possibilità di gestire migliaia di utenti contemporaneamente)
- GFDM (e.g. regional areas)
- Full Duplex (e.g. relay, reti cognitive)

New service enabling
- D2D (per servizi di Public Safety, Community Services, Vehicle-to-X)
- FBMC (eliminazione del prefisso ciclico quindi riduzione della latenza (e.g. automotive), aumento complessità)
- GFDM (e.g. regional areas)
- D2D for IoT

Enormous traffic growth

New services
Conclusions

- Several solutions from 5G
  - Flexible air interface
  - Smart spectrum usage
  - Multi antenna Tx/Rx
  - Versatile network solutions

- Solutions to increase the throughput
  - Massive MIMO, mmWave
  - GFDM (flexibility for several waveforms, higher spectral efficiency then bit rate)
  - Full duplex (doubling the data rate)
  - SEFDM (spectrum optimization)

- Solutions to enhance the amount of device management
  - NOMA (usable for different user types)
  - FBMC, GFDM
    - confined spectrum → use of spectrum not assignable with OFDM;
    - Loose synchronization is required → possibility to simultaneously manage thousand of devices without the access control)

- Solutions to enable new services
  - D2D → Automotive, Public Safety, …
  - Full Duplex → improve the spectrum usage, relays, cognitive networks, …
  - Enhancement in IoT → novel applications, …

Thank you for your attention! Any question?
References

- G. Fettweis, “5G What will it be”, ICC 2013