Introduction to Multi-User Superposition Transmission (MUST) in 3GPP LTE-A

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Outline

- 3GPP Standardization Introduction
- 5G Activity in 3GPP
- Multiple Access Technique
- Review NAICS in Rel-12
- Non-Orthogonal Multiple Access
- MUST Status in 3GPP
3GPP Standardization Introduction
3GPP Standardization

- 3GPP organization
3GPP Standardization

- Standardization phases and iterative process
3GPP Standardization

- Release of 3GPP specifications


- Release 99: W-CDMA
- Release 4: 1.28Mcps TDD
- Release 5: HSDPA
- Release 6: HSUPA, MBMS
- Release 7: HSPA+ (MIMO, HOM etc.)
- Release 8: LTE
- Release 9: Minor LTE enhancements
- Release 10: LTE-Advanced
- Release 11: Under preparation

ITU-R M.1457: IMT-2000 Recommendation
ITU-R M.[IMT.RSPEC]: IMT-Advanced Recommendation
3GPP Standardization

- LTE Release 8 Standardization History

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<thead>
<tr>
<th>Year</th>
<th>Q3</th>
<th>Q4</th>
<th>Q1</th>
<th>Q2</th>
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- Study Item
- Work Item
- 3GPP TSG meeting

- Study Item "Evolved UTRA and UTRAN" Approved.
- Work Item "3G Long-term Evolution" approved.
- Requirements approved
- Core specs approved
- Test specs approved
- Core specs functionally frozen
- Main work items closed
- ASN.1 frozen
## 3GPP Standardization

### Technical Features

<table>
<thead>
<tr>
<th>Release</th>
<th>Features</th>
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</thead>
<tbody>
<tr>
<td>8</td>
<td>OFDMA Air Interface</td>
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</table>
| 9       | LTE Femtocell (HeNB)  
            Dual layer BF (TM8)  
            MBMS |
| 10      | Carrier Aggregation (CA)  
            Enhanced Downlink Transmission  
            - Eight-layer Spatial Multiplexing including UE-specific RS (TM9)  
            - Channel State Information Reference Symbols (CSI-RS)  
            Enhanced Inter-cell Interference Coordination (eICIC)  
            Machine Type Communications (MTC) |
| 11      | eCA  
            FeICIC  
            eDL MIMO (TM10)  
            CoMP  
            eMTC |
# 3GPP Standardization

## Technical Features

<table>
<thead>
<tr>
<th>Release</th>
<th>Features</th>
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<tr>
<td>12</td>
<td>Small Cell Enhancement based on Inter-cite CA&lt;br&gt;New Carrier Type (NCT)&lt;br&gt;UE-specific Elevation BF / 3D-MIMO&lt;br&gt;NAICS&lt;br&gt;DL eCoMP&lt;br&gt;LTE-WLAN integration&lt;br&gt;LTE-Direct (D2D) for Public Safety&lt;br&gt;Low Cost MTC</td>
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<td>13</td>
<td>Rel-13 LTE Carrier Aggregation&lt;br&gt;RAN Sharing Enhancements&lt;br&gt;Study on Enhanced Multiuser Transmissions and Network Assisted Interference Cancellation for LTE&lt;br&gt;...</td>
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5G Activity in 3GPP
5G Timeline in 3GPP

- Evaluation criteria
- Requirements
- Initial submissions of proposals
- IMT-2020 specifications

- RAN SI: scope & requirements
- channel modeling
- RAN WG SI: evaluation of solutions
- RAN WG WI: specification of solutions
- SA system work
- SA1 SMARTER SI
- SA1 SMARTER WI
- HSPA/LTE evolution

- RAN Workshop
- RAN-SA Workshop
- RAN#70 Dec 15
- 5D#23 Feb 16
- RAN#72 Jun 16
- 5D#26 Feb 17
- 5D#27 Jun 17
- 5D#28 Oct 17
- 5D#31 Oct 18
- 5D#32 Jun 19
- 5D#34 Feb 20
- 5D#36 Oct 20

- IMT 2020

- RAN#69 Sep 15
- 5D#23 Feb 16
- RAN#72 Jun 16

- RAN#69 Sep 15
- 5D#23 Feb 16
- RAN#72 Jun 16

- IMT-2020 specifications
- Evaluation criteria
- Requirements
- Initial submissions of proposals
- IMT-2020 specifications

- Evaluation
- IMT-2020 specifications
A 5G Workshop has been held in Phoenix this week. 550 delegates and over seventy presentations contributed to the discussion, which covered the full range of requirements that will feed TSG RAN work items for the next five years.

In his Workshop Summary (RWS-150073), Dino Flore, RAN Chairman and Workshop Chair, highlighted three high level use cases to be addressed:

- Enhanced Mobile Broadband
- Massive Machine Type Communications
- Ultra-reliable and Low Latency Communications
5G Scenarios and Challenges

Mainly for Mobile Internet
- Seamless Wide-Area Coverage
  - User experienced data rate: 100 Mbps
- High-Capacity Hot-Spot
  - User experienced data rate: 1 Gbps
  - Peak data rate: Tens of Gbps
  - Traffic volume density: Tens of Tbps/km²

Mainly for IoT (new scenarios)
- Low-Latency High-Reliability
  - Air interface latency: 1 ms
  - Reliability: nearly 100%
- Low-Power Massive-Connections
  - Connection density: $10^6$ / km²
  - Ultra-low power consumption/Ultra-low cost
Envisioned Market Space @ 2020

- Enhanced Mobile Broadband
  - Overall smartphone market space keep growing steadily
  - Premium phones could support 5G ultra high speed as selling point

- Massive Machine Type Communication
  - Overall IoT market space grows fast
  - Significant growth on LPWA (Low Power Wide Area) market segment
    - 5G massive MTC could be the solution to address this market

- Ultra-Reliable and Low Latency Communication
  - Market just initiated, need short term solution to test market.
  - 5G solution could be long-term roadmap for ultimate performance

Source:

Potential space for 5G enhanced mobile broadband

Source: Statista

45% CAGR 2014–2019

Potential space for 5G massive MTC

Source: Cisco VNI
All Things Connected

New access scheme based on contention is promising

- Less overhead, shorter latency suitable for bursty small packets
- Contention based access for latency and capacity (connection density) improvements
  - Avoid TA adjustment by longer symbol length (smaller sub-carrier)

Scheduled Access

Contention Access

Scheduling Command

Data Transmission

Source:
Multiple Access Technique
Multiple Access & Orthogonality

- TDMA, FDMA, CDMA
- OFDMA
Multiple Access Technique

- SDMA (Multi-User MIMO, MU-MIMO)
  - Codebook based MU-MIMO (TM5)
  - Non-Codebook based MU-MIMO (TM8&9)

- Inter-user interference
  - Limited CSI feedback in FDD
  - Low-resolution beam
  - Solution: complicated receiver (e.g., SIC or Near-ML)?

<table>
<thead>
<tr>
<th>Rel-8</th>
<th>Rel-9</th>
<th>Rel-10</th>
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<tbody>
<tr>
<td>Codebook-based TM5</td>
<td>Non-codebook-based TM8</td>
<td>Non-codebook-based TM9</td>
</tr>
<tr>
<td>• Precoding weight are</td>
<td>• eNB can use any precoding weight(s)</td>
<td>• Support 8-Tx codebook-based feedback using CSI-RS</td>
</tr>
<tr>
<td>chosen from a predefined PMI</td>
<td>• UE relies on DMRS</td>
<td></td>
</tr>
<tr>
<td>• PMI signaled to desired user only</td>
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MA Technique Challenge in 5G

- Mobile Broadband => Enhance data rate
- Massive MTC => Massive connection
- More challenging in 4G and future 5G
- *Non-orthogonal* MA both in DL and UL is proposed and investigated
Review NAICS in Rel-12
NAICS in Rel-12

3GPP TR 36.866 V12.0.1 (2014-03)

Technical Report

3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on Network-Assisted Interference Cancellation and Suppression (NAIC) for LTE (Release 12)
NAICS in Rel-12

- Inter-Cell Interference
- Advanced receiver
- Network-assisted information/signalling
- A tradeoff between performance, complexity, signalling overhead

NAICS scenarios:

<table>
<thead>
<tr>
<th>NAICS scenario 1</th>
<th>NAICS scenario 2a</th>
<th>NAICS scenario 2b</th>
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<tbody>
<tr>
<td>Homogeneous scenario</td>
<td>Non-ideal connection Heterogeneous scenario 2a</td>
<td>“fiber acces 4” connection Heterogeneous scenario 2b</td>
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</tbody>
</table>
NAICS Receiver

System Model:

\[ y = H_0 x_0 + H_1 x_1 + \left( \sum_{i=2}^{K} H_i x_i \right) + n \]

\[ = H_0 x_0 + H_1 x_1 + z \]

\[ = H_0 x_0 + v \]

Receiver Structure 1: Interference Suppression (IS) Receivers

- LMMSE-IRC (No knowledge of interferer parameters is required)
- Enhanced LMMSE-IRC (E-LMMSE-IRC)
  \[ W = \hat{H}_0^H \left( \hat{H}_0 \hat{H}_0^H + \hat{H}_1 \hat{H}_1^H + \hat{R}_Z \right)^{-1} \]
- Widely linear MMSE-IRC (WLMMSE-IRC)
  - Bring the most benefit when the dominant interferences use PAM
NAICS Receiver

- Receiver Structure 2: Maximum-Likelihood Receivers
  - ML
    - Full-blown joint detection of useful and interference signals in accordance to the ML criterion
  - Reduced complexity ML (R-ML)
    - Reduced complexity joint detection of useful and interference modulation symbols in accordance to the ML criterion
  - Iterative R-ML
    - Iterative MAP detection and decoding of useful and interference signals. Both successive and parallel processing implementations may be applied.
    - Assumptions on network coordination may be necessary.

\[
y = H_S P_S x_S + H_C P_C x_C + \sum_k H_k P_k x_k + n = \begin{bmatrix} H_S P_S & H_C P_C \end{bmatrix} \begin{bmatrix} x_S \\ x_C \end{bmatrix} + \sum_k H_k P_k x_k + n = Hx + n'
\]
Receiver Structure 3: Interference Cancellation (IC) Receivers

- Linear Code word level SIC (L-CWIC)
  - Utilizing successive application of linear detection, decoding re-encoding and cancellation
  - Having iteration (ex: Turbo L-CWIC)
  - Utilizing CRC check (ex: hard L-CWIC)
  - Assumption on network coordination may be necessary

- ML CWIC
  - Same description as L-CWIC except the receiver utilizing successive application of ML or reduced complexity ML detection.

- Symbol level IC (SLIC)
  - Utilizing successive application of linear detection, reconstruction and cancellation.
    - May have iteration

- Parallel interference cancellation (PIC)
  - PIC as opposed to SIC, otherwise similar to SIC
  - PIC receiver can be categorized into L-CW-PIC, ML-CW-PIC or SL-PIC similar to SIC
NAICS Receiver

- Linear Code word level SIC (L-CWIC)

- Symbol level IC (SLIC)
Non-Orthogonal Multiple Access (NOMA) 
or 
Multi-User Superposition Transmission (MUST)
Non-Orthogonal Multiple Access

- **Downlink** is discussed first in 3GPP
- A special implementation of MU-MIMO
- Users signals are separated in “power domain”
- Interference-cancellation receiver required
Non-Orthogonal Multiple Access

- Transmission signals:

\[ x = \sqrt{P_1 s_1} + \sqrt{P_2 s_2} \]
Non-Orthogonal Multiple Access

Exemplified comparison between OMA and NOMA

OMA → α = 0.5, \( P_1 = P_2 = 0.5 \)
NOMA → \( P_1 = 0.2, \ P_2 = 0.8 \)

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<tr>
<th></th>
<th>OMA</th>
<th>NOMA</th>
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<tbody>
<tr>
<td>( R_1 )</td>
<td>1.6646</td>
<td>2.1962</td>
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<tr>
<td>( R_2 )</td>
<td>0.25</td>
<td>0.3685</td>
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</table>
Non-Orthogonal Multiple Access

- To combine NOMA with MIMO
  - MMSE-IRC: Suppress the inter-beam interference
  - SIC: Cancel intra-beam interference
Non-Orthogonal Multiple Access

- Possible use cases of NOMA (source: NTT DOCOMO)
Non-Orthogonal Multiple Access

- 2-User broadcast channel
  - Capacity of **orthogonal** transmission

\[ R_k < \log \left( 1 + \frac{P|h_k|^2}{N_0} \right), \quad k = 1, 2. \]
Non-Orthogonal Multiple Access

- 2-User broadcast channel
  - Non-Orthogonal example: Superposition coding & SIC receiver

Question: whether legacy UE can join NOMA?

Source: Huawei
Non-Orthogonal Multiple Access

- 2-User broadcast channel
  - Illustration of superposition
Non-Orthogonal Multiple Access

- 2-User broadcast channel
  - NOMA Capacity

\[ R_1 = \log \left( 1 + \frac{P_1|h_1|^2}{P_2|h_1|^2 + N_0} \right) \text{ bits/s/Hz}, \]

\[ R_2 = \log \left( 1 + \frac{P_2|h_2|^2}{N_0} \right) \text{ bits/s/Hz}. \]

Sum rate vs Fairness
Slow and limited fluctuations 😞
Non-Orthogonal Multiple Access

Superposition coding implementation

Definition (Code Library)
A collection of \( M < \infty \) encoder-decoder function pairs with spectral efficiencies (aka "rates") \( r_1 < r_2 \cdots < r_M \)

Definition: Packet Error Rate (PER)
The probability of codeword decoding error

Definition (\( \epsilon \)--Feasible on a Link)
A code with rate \( r \) is \( \epsilon \)--feasible on a link if the PER of a codeword encoded at \( r \) is no greater than \( \epsilon \)

Non-Orthogonal Multiple Access

- Superposition coding implementation

\[
\begin{align*}
\gamma_N &= 15 \text{ dB}, \quad \gamma_F = 8 \text{ dB} \\
E &= (0, r_8) \\
D &= (r_5, r_7) \\
C &= (r_7, r_3) \\
B &= (r_5, r_5) \\
A &= (r_2, 0)
\end{align*}
\]
MUST Status in 3GPP
The study item entitled “Enhanced Multiuser Transmissions and Network Assisted Interference Cancellation” was approved in RAN plenary #66 (Dec 2014)
  * Later rename as Study on **Downlink** MultiUser Superposition Transmission (MUST) for LTE

This study item will be kicked off in RAN1#80bis (April 2015) with respective objectives defined in the SID,

The target completion date is RAN#70 in December 2015.
Focus on MUST

- Implementation issues of multiple access
  - Comparison metric
    - Center user, edge user, sum rate
    - Fairness
    - Delay
    - Receiver complexity
    - Scheduling flexibility
    - Signalling overhead
  - Channel measurement and feedback
  - Transmitter requirement (EVM constraint)
NOMA

- Linear Superposition coding (NOMA)

Different bits allocated to different users

Adjacent points are not Gray-mapped
Non-linear Superposition coding (SOMA)
Rema

Rate-Adaptive Constellation Expansion MA (RA-CEMA)

Source: Huawei
Transmission Schemes

- MUST Category 1: Superposition transmission with adaptive power ratio on component constellations and non-Gray-mapped composite constellation
  - MediaTek, Huawei, Intel, LGE, NTT DoCoMo, Xinwei
- MUST Category 2: Superposition transmission with adaptive power ratio on component constellations and Gray-mapped composite constellation
  - Huawei, ZTE, Samsung, LGE, MediaTek, NTT DoCoMo
- MUST Category 3: Superposition transmission with label-bit assignment on composite constellation and Gray-mapped composite constellation
  - Huawei, Qualcomm, Nokia
Traffic Models for Evaluation

- **FTP traffic model 1** with
  - Packet size of 0.1 Mbytes for resource utilization of 60%, 80% and 90%, and
  - Packet size of 0.5 Mbytes for resource utilization of 60%
  - Statistics of the number of UEs simultaneously scheduled in a subframe should be reported
  - Duration of the simulation should also be reported in terms of the number of subframes

- Companies are also free to submit **full buffer traffic model results**
  - RAN1 will not draw conclusions of performance gains from full buffer traffic model results
Receiver Assumptions

- Each company should describe UE receiver assumptions in MUST scheme
  - As an example, in MUST scheme,
    - For all users, MMSE-IRC is assumed for inter-cell interference suppression
    - For MUST near-users the following is assumed
      - Either SLIC/R-ML or CWIC for intra-spatial-layer interference cancellation
      - Either MMSE-IRC or R-ML/SLIC is assumed for inter-spatial-layer interference suppression for MU-MIMO, and both MMSE and R-ML/SLIC are assumed for inter-spatial-layer interference suppression for SU-MIMO
    - For other users, MMSE-IRC is assumed for inter/intra-spatial-layer interference suppression
## MUST Status in 3GPP

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<th>Location</th>
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<td>RAN#69</td>
<td>14 – 17 September 2015</td>
<td>Phoenix</td>
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<tr>
<td>RAN1#82bis</td>
<td>5 – 9 October 2015</td>
<td>Malmo</td>
<td>5-week gap</td>
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<td>RAN1#83</td>
<td>16 – 20 November 2015</td>
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Go to Work Item and 5G (?)
Thank You for Your Attentions!

Comment and/or Question?