Non-orthogonal Multiple Access (NOMA) for Future Radio Access

Kenichi Higuchi
Tokyo University of Science
Evolution of Radio Access (1)

- Non-orthogonal multiple access (NOMA) based on DS-CDMA for 3G
  - Rake diversity in multipath fading channel appropriate for low-rate data (thus large spreading factor)
  - Large capacity via statistical multiplexing effect for circuit-switching voice users

- Orthogonal multiple access (OMA) based on OFDM for 3.9G and 4G
  - High robustness against multipath interference with simple receiver structure (e.g. by using frequency-domain channel equalization)
  - Channel-aware packet scheduling in both frequency and time domain \(\Rightarrow\) multiuser diversity
  - Good affinity to the MIMO channel transmission (again assuming relatively simple receiver structure)
What about beyond 4G?

We think that NOMA with more advanced transceiver can be a candidate multiple access scheme.

- In theory, NOMA with successive interference cancellation (SIC) achieves the multiuser capacity region.
  - Especially important for improving the performance of cell-edge users with small system efficiency loss
- OFDM-like signaling with superposition coding
OMA vs. NOMA

**OMA**
- User A’s signal, $x_A$
- User B’s signal, $x_B$

<table>
<thead>
<tr>
<th>Frequency</th>
</tr>
</thead>
</table>

- ✓ Narrow transmission bandwidth per user
- ✓ No inter-user (intra-cell) interference

**NOMA with SIC**
- User A’s signal, $x_A$
- User B’s signal, $x_B$

<table>
<thead>
<tr>
<th>Frequency</th>
</tr>
</thead>
</table>

- ✓ Wide transmission bandwidth per user
- ✓ With inter-user (intra-cell) interference
- ✓ No inter-user (intra-cell) interference

SIC (successive interference cancellation) at the receiver

$x_A + x_B + \text{noise} 
\xrightarrow{-x_B + \text{noise}} \xrightarrow{\text{Decode of } x_A} x_A
\xrightarrow{\text{Decode of } x_B} x_B
NOMA, namely “downlink Multi-User Superposition Transmission (MUST)” is now being discussed at the standardization body such as 3rd Generation Partnership Project (3GPP) as a further evolution of LTE, i.e., LTE Release 13.


In the following, we will briefly explain the principle of downlink NOMA and our investigations, along with several issues for implementing NOMA in real systems.

Downlink
Principle of Downlink NOMA (1)

- Base station (BS) transmitter performs superposition coding for non-orthogonal user multiplexing.
  - Each user’s information is independently channel coded and modulated and then added with other users’ signals.

$$x = \sum_{u=1}^{K} \sqrt{p_u} s_u$$

Tx power for user $u$  Coded modulation symbol of user $u$
Principle of Downlink NOMA (2)

- The user terminal conducts SIC.
  - In the downlink, the decoding order of SIC should be in the order of increasing channel gain, $|h_k|^2/N_k$.
  - Each user can remove interference from the user whose channel condition is worse than that user.

Received signal at user $k$:

$$y_k = h_k x + w_k$$

$$= h_k \sum_{u=1}^{K} \sqrt{p_u} s_u + w_k$$

Channel coefficient of user $k$  Noise + inter-cell interference (Power = $N_k$)
The user terminal conducts SIC.

- User \( k \) can correctly decode user \( 1 \sim k-1 \) signals and remove these signal components from the received signal.

The received signal at user \( k \):

\[
y_k = h_k x + w_k = h_k \sum_{u=1}^{K} \sqrt{p_u} s_u + w_k
\]

Channel coefficient of user \( k \)

Noise + inter-cell interference

(Power = \( N_k \))

Principle of Downlink NOMA (2)

\[
R_{k}^{(\text{NOMA})} = \log_2 \left( 1 + \frac{p_k |h_k|^2}{\sum_{u=k+1}^{K} p_i |h_k|^2 + N_k} \right) \text{ b/s/Hz}
\]
Capacity Region

Symmetric channel

\[ p_{\text{total}} |h_1|^2/N_1 = 10 \text{ dB} \]
\[ p_{\text{total}} |h_2|^2/N_2 = 10 \text{ dB} \]

Asymmetric channel

\[ p_{\text{total}} |h_1|^2/N_1 = 20 \text{ dB} \]
\[ p_{\text{total}} |h_2|^2/N_2 = 0 \text{ dB} \]

✓ Capacity regions of two access schemes are identical.

✓ Capacity region of NOMA is wider than that of OMA.
System Efficiency and User Fairness

◆ Generalized system throughput based on $\alpha$-proportional fair

$$ U(t) = \sum_{k=1}^{K} \frac{\bar{R}_k(t)^{1-\alpha}}{1-\alpha} $$

– Parameter $\alpha$ controls the tradeoff between the system efficiency and user fairness.

To maximize the system throughput, the following resource allocation metric is to be maximized.

$$ M(W,P;t) = \sum_{k=1}^{K} \frac{1}{\bar{R}_k(t - 1)^\alpha} R_k(W,P;t) $$

As $\alpha$ is increased for better user fairness, weight for throughput of weak user increases.
When NOMA is Effective?

NOMA is more attractive than OMA when the user channels are asymmetric and the system wants to take care of user fairness.
NOMA in Cellular Downlink

◆ In cellular downlink, the channel conditions vary significantly among users due to the near-far effect.

◆ When we want to improve the throughput of weak user …
  – In OMA, bandwidth allocation to strong user is severely limited.
  – NOMA with SIC
    • Wide transmission bandwidth for all users
    • Allocates large power to weak user
      – Although the weak user does not use SIC, the impact of inter-user interference is small.
    • Strong user uses SIC to cancel out the interference from weak user and small power allocation is enough due to strong channel.
Example

Full-buffer traffic model with 10 users per cell

FTP traffic model 1 with $\lambda = 0.8$

- OMA
- NOMA
NOMA in MIMO Downlink

Key issues in our mind

- Use of SIC instead of dirty paper coding (DPC)
  - DPC is difficult to implement and sensitive to the error in channel state information feedback.

- Avoidance of increase in reference signaling overhead
  - In NOMA, the number of users multiplexed within a same frequency is assumed to be beyond the number of BS antennas.
  - If we assume the user-specific beamforming, the number of reference signals in NOMA may exceed the number of BS antennas.
Proposed Method

BS transmitter: Intra-beam superposition coding
- The number of beams is equal to that of BS antennas.
- Within a beam, multiple-user signals are non-orthogonally multiplexed based on superposition coding.
  - The number of reference signals is the same as in OMA irrespective of the number of non-orthogonally multiplexed users.

UE receiver: Intra-beam SIC
- Inter-beam interference is suppressed by the linear spatial filtering.
- Then, intra-beam interference due to superposition coding is removed by SIC.
  - Effective use of SIC as in the SISO or SIMO downlink
Pictorial Example

Beam 1
- Signal to User1
- Signal to User2

Beam 2
- Signal to User3
- Signal to User4

User 1
- Spatial filtering
- SIC of User 2 signal
- User1 signal decoding

User 2
- Spatial filtering
- User2 signal decoding

User 3
- Spatial filtering
- SIC of User 4 signal
- User3 signal decoding

User 4
- Spatial filtering
- User4 signal decoding

Equivalent normalized channel gain, $g$

Large

Small

February 26, 2016
Kenichi Higuchi/TUS@Adachi_WS
Throughput Performance

![Graph showing sum throughput (Mb/s) and cell-edge user throughput (kb/s) for different numbers of users per cell and different numbers of BS antennas. The graphs compare NOMA and OMA.]
Issues and recent investigations for implementing NOMA in real systems
Generation of Superimposed Signal (1)

- Two approaches under investigation at 3GPP
  
  - **SOMA (semi-orthogonal multiple access)**
    
    3GPP R1-151848, “Candidate schemes for superposition transmission,” Apr. 2015.
    
    Each user’s information is QAM modulated and summed among users with appropriate power allocations so that the resultant signal still forms higher-order QAM signal.
    - E.g. QPSK + QPSK = 16QAM, 16QAM + QPSK = 64QAM
Generation of Superimposed Signal (2)

◆ **SOMA (semi-orthogonal multiple access) cont’d**
  – No need for defining new modulation symbols
  – Good performance even when SIC is not applied
  – Question: Do we need Gray mapping after superposition?

◆ **RA-CEMA (rate-adaptive constellation expansion multiple access)**
  – Superimposed signal forms $2^m$QAM similar to SOMA.
  – Mapping of coded bits of multiple users on $m$ bits at $2^m$QAM modulation is adaptively controlled depending on the channel conditions of respective users.
Generation of Superimposed Signal (3)

- RA-CEMA (rate-adaptive constellation expansion multiple access) cont’d
  - No need for defining new modulation symbols similar to SOMA
  - By changing the bit mapping of multiple non-orthogonally multiplexed users based on channel conditions, more detailed rate control is achieved.

Far user = 1 bit
Near user = 3 bits
Others

◆ Resource allocation
   – In addition to the time/frequency block allocation in OMA, the power allocation needs to be appropriately conducted.
   – Frequency block-distributed codeword mapping in LTE-Advanced should also be taken into account.

◆ Control signaling
   – Transport format (modulation scheme, code rate, power, etc.) of other users should be informed for SIC process.

◆ Reference signaling
   – Additional format of reference signal appropriate for NOMA may be defined.

◆ Hybrid ARQ in NOMA
Conclusion

We briefly explained the principle of downlink NOMA and our investigations, along with several issues for implementing NOMA in real systems.

Thank you very much for your kind attention!