DNN-based Active User Detection for a NB-IoT Compatible Grant Free NOMA System

Progress Seminar

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- The algorithm was initially simulated and tested in Matlab.
- In the next phase, Matlab code was translated into C code.

Introduction to grant free NOMA

Definition

Massive machine type communication (mMTC) refers to the connection of a large number of devices (10^6 devices per km^2 [a]) to the base station (BS).

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- In mMTC majority of the devices are
  - Low cost
  - Battery powered
  - Transmits low data sporadically.
- Main concern of mMTC is massive connectivity of the devices to the BS.

Introduction to grant free NOMA

Existing access method: Grant based OMA

- **Grant based access** : Each device requests a data transmission slot via a contention-based random access process.
- **Orthogonal multiple access (OMA)** : Available radio resources are allocated to devices in a non over lapping manner.

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Why grant based access OMA is not suitable for mMTC?

- Limited number of available radio resources.
- Signalling overhead.

Introduction to grant free NOMA

Solution : Grant free non-orthogonal multiple access

- **Grant free** access, allows devices to transmit data without the scheduling process.
- **NOMA** enables massive connectivity over limited radio resources[a].

---

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- In typical grant free system
  - Preamble and data are transmitted simultaneously.
  - Active user detection plays major role in successful data decoding.

Grant free NOMA system

- A typical uplink mMTC with one BS serving a total of M users is considered.

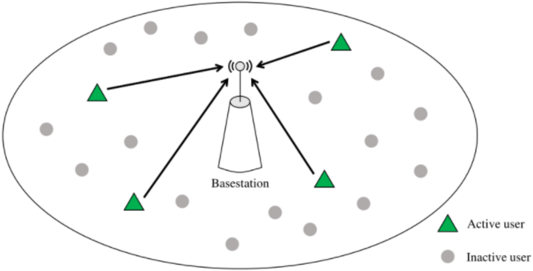

Figure: mMTC uplink scenario where only a few devices are active[1].

- Number of active users : Poisson with mean λ.

[1] Wonjun Kim et al. "Deep neural network-based active user detection for grant-free NOMA systems". In: *IEEE Trans. Commun.* (2020).

Grant free NOMA system contd.

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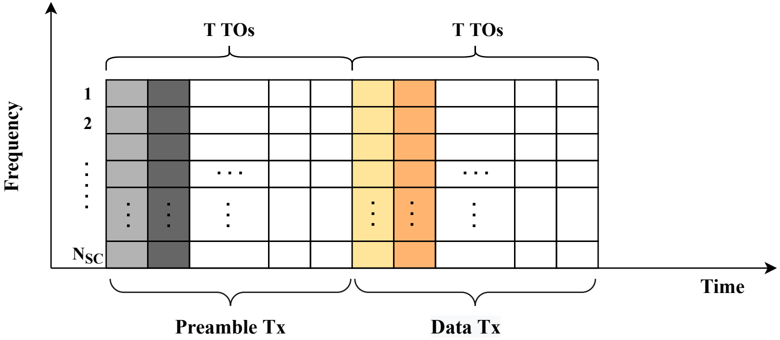
Choosing number of preambles

$$N_{\mathrm{p}} = \left\lceil \frac{\lambda^2}{2\log(1/\mathbb{E}[p_{\mathrm{all}}])} \right\rceil$$

N_{p} : Number of preambles,
$\mathbb{E}[p_{\mathrm{all}}]$: Desired average success (no collision) probability[a].

[a] GS Harini et al. "On Preamble-based Grant-Free Transmission in Low Power Wide Area (LPWA) IoT Networks". In: *Proc. IEEE 6th World Forum Internet Things*. IEEE. 2020, pp. 1–6.

Time-frequency resource grid



- Each TO is associated with set of N preambles, $\mathbb{P} = \{\mathrm{P}_1, \ldots, \mathrm{P}_N\}$.

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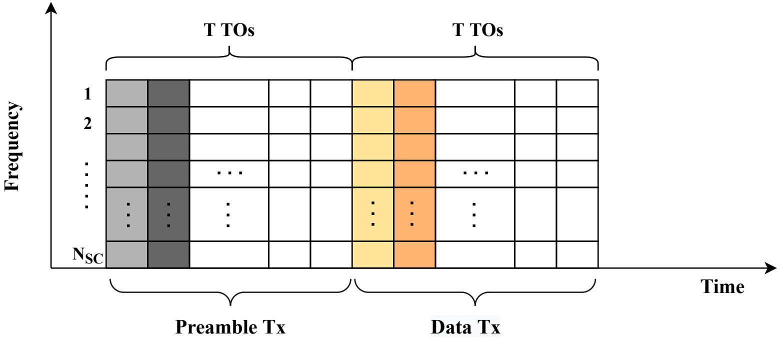

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- Here N and T are chosen such that $NT \geq N_{\mathrm{p}}$.

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Transmitted signal

Signal transmitted by the user choosing i^{th} preamble sequence,

$$x_i(n) = \frac{1}{N_{\mathrm{FFT}}} \sum_{m=0}^{N_{\mathrm{FFT}}-1} \mathrm{P_i}(m) e^{j\frac{2\pi nm}{N_{\mathrm{FFT}}}}$$

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Signal at base station (BS)

Superimposed signal received at the BS in any TO with k active users,

$$y(n) = \sum_{i=1}^{k} h_i e^{j2\pi r_i n} x_i(n - d_i) + w(n)$$

h_i : Flat-fading channel coefficient, r_i : Normalized residual carrier frequency offset and d_i : Timing offset of i^{th} user.

Conventional receiver architecture for AUD

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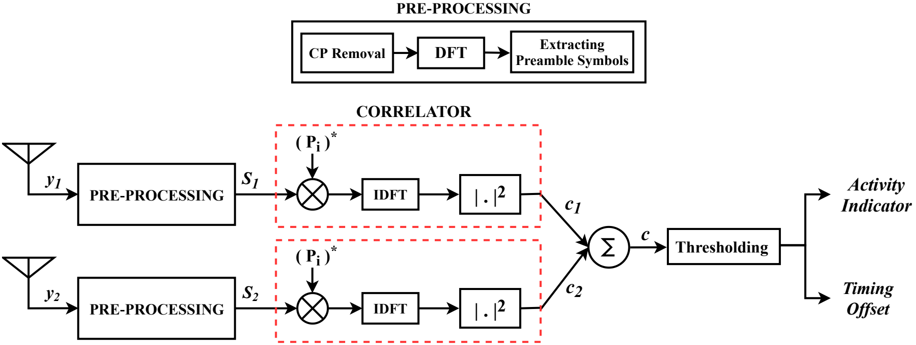

** The "correlator" block will be replaced by DNN in DNN-based AUD.

DNN based AUD

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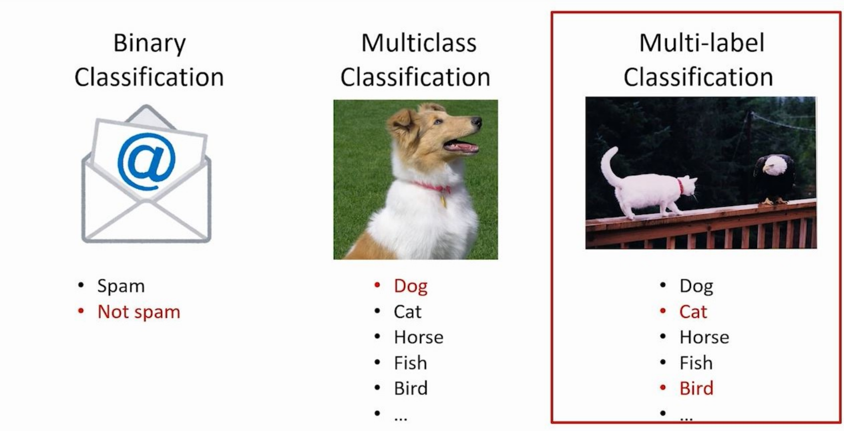
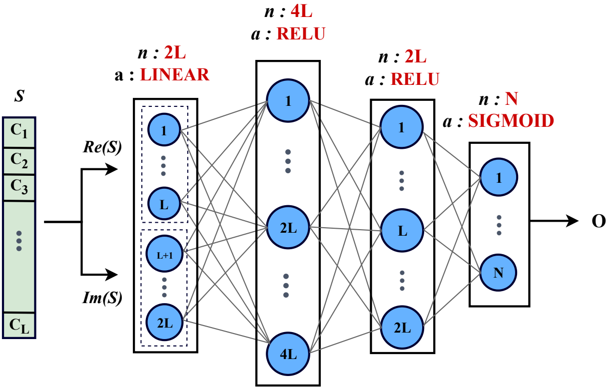


Source : https://www.microsoft.com/en-us/research/uploads/prod/2017/12/40250.jpg

DNN architecture



DNN Training Parameters	
Loss function	Binary Cross Entropy
Optimizer	ADAM
Batch size	1024
Epochs	75
Learning rate	0.001

***n* : Number of Neurons**
***a* : Activation Function**

** $\mathbf{O} = [o_1, \ldots, o_{\mathrm{N}}]$, where $o_i \in [0, 1]$.

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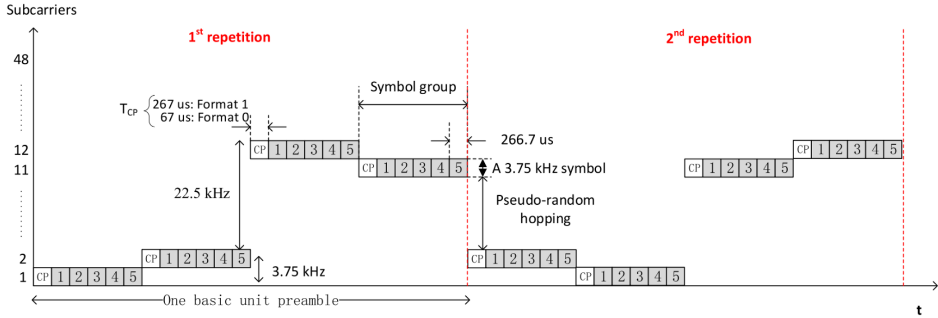
- Tested on dataset from different SNR values.
- Outputs from two antenna chain (before thresholding) is averaged to get final output.

Simulation parameters



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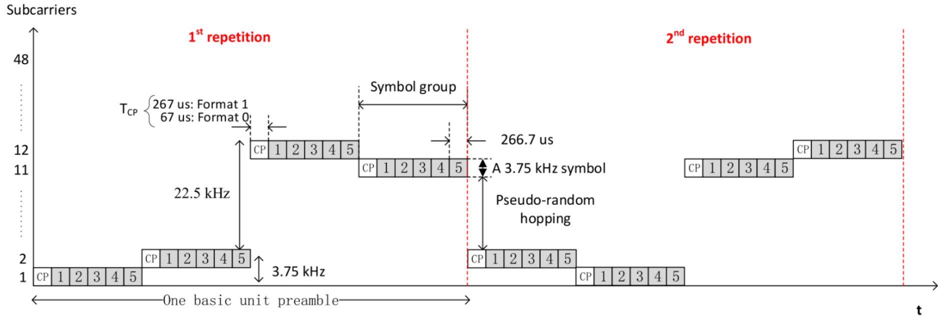

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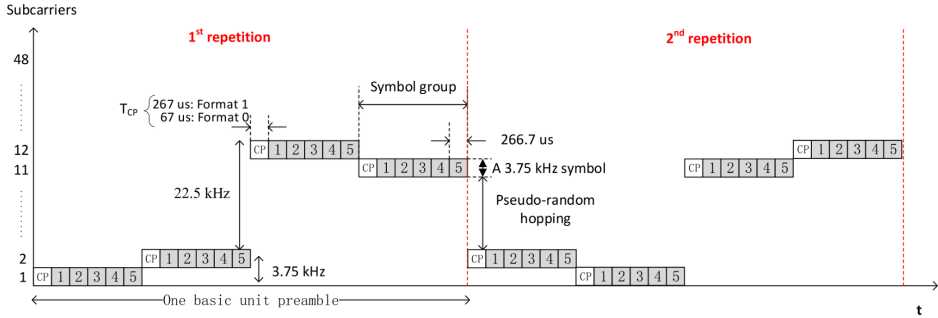

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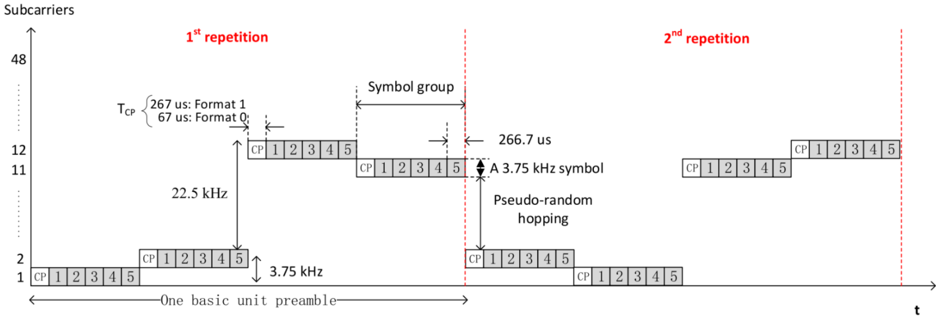

- Configuration same as that of coverage area (CVA) 1 of NB-IoT is considered.
- Number of TOs is chosen to be 40.
- Each TO is of 1 OFDM symbol duration.
- With this setting $K = 2$ i.e, $\mathbb{P}(k \leq 2) \geq 0.99$.

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Bandwidth, B	180 KHz
Subcarrier spacing, Δf	3.75 KHz
Number of subcarriers, N_{SC}	48
N_{FFT} and N_{CP}	512 and 32 samples
Antenna configuration	1 Tx; 2 Rx
Channel model	EPA 1 Hz
Timing offset	rand(0, N_{CP}) samples
Frequency offset	rand(-200, 200) Hz
Average success probability	0.9
Number of TOs, T	40
Preamble length, L	47
Average number of users, λ	18

Performance metrics

All-user success probability:
Probability of all active users in a TO being detected correctly.

Per-user success probability:
Probability of successful detection of an individual user.

False alarm probability:
Probability of wrongly detecting a user when only noise is present.

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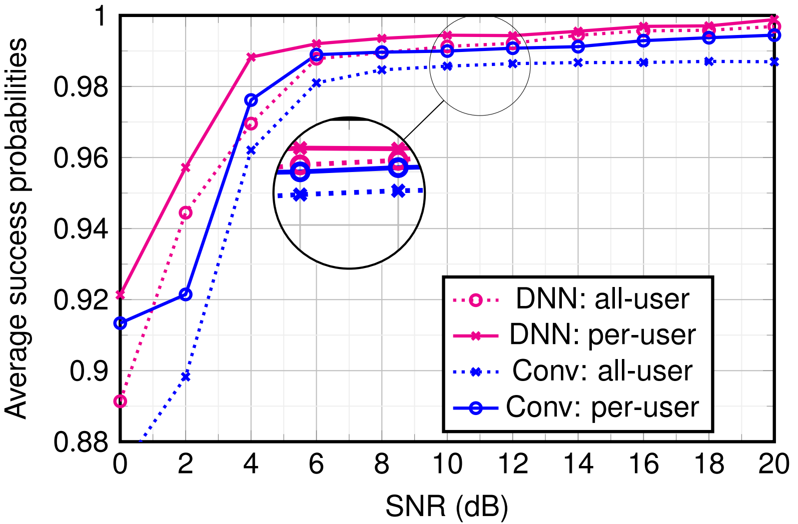
Performance requirements of NB-IoT

- Per-user success probability ≥ 0.99
- False alarm probability ≤ 0.001

at 6 dB SNR for CVA 2 and approximately 12 dB SNR for CVA 1 in extended pedestrian A (EPA) channel[a].

[a] 3GPP. *LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception*. TS 36.104. 3GPP, 2017.

Results



** It is observed that false alarm probability of both methods were below 0.001 for SNR $\geq$ 6dB.

Computational complexity

- Number of real floating point operations required is considered.

[2] Steven G. Johnson et al. "A Modified Split-Radix FFT With Fewer Arithmetic Operations". In: *IEEE Trans. Signal Process.* (2007).

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- $\approx N \times (6L + \frac{34}{9} \times N_{\mathrm{FFT}} \log_2(N_{\mathrm{FFT}}))^2$

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- $\approx 32L^2 + 4LN + K \times (6L + \frac{34}{9} \times N_{\mathrm{FFT}} \log_2(N_{\mathrm{FFT}}))$

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** It is observed that the proposed method is ≈ 7 times computationally less complex compared to conventional method.

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- A GF-NOMA scheme compatible with NB-IoT was presented.

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- DNN-based AUD was discussed, which has the following advantages
  - Works well in in the presence timing and frequency offsets.
  - Its performance is comparable or better than the conventional AUD scheme for flat-fading (and low mobility) channels.
  - Its complexity is much smaller than the conventional scheme.
  - It meets the performance criteria of NB-IoT in both CVA 1 and 2.

Future work

NPRACH detection algorithm

- Analyzing the suitability of the implemented NPRACH detection algorithm in non terrestrial network (NTN) based communication system.

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Proposed GF-NOMA scheme

- Extending the proposed solutions to CVA 3 of NB-IoT.
- Exploring adaptive threshold based multi label classification.
- Exploring different preamble lengths.
- Designing a unified DNN based architecture incorporating collision detection along with AUD.
- Analyzing the suitability of the proposed method in NTN scenario.

Thank you!