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SOFTWARE DEFINED RADIO IMPLEMENTATION OF ADAPTIVE NONLINEAR DIGITAL SELF-INTERFERENCE CANCELLATION FOR MOBILE INBAND FULL-DUPLEX RADIO

Mona AghababaeeTafreshi, Matias Koskela, Dani Korpi, Pekka Jääskeläinen, Mikko Valkama, and Jarmo Takala
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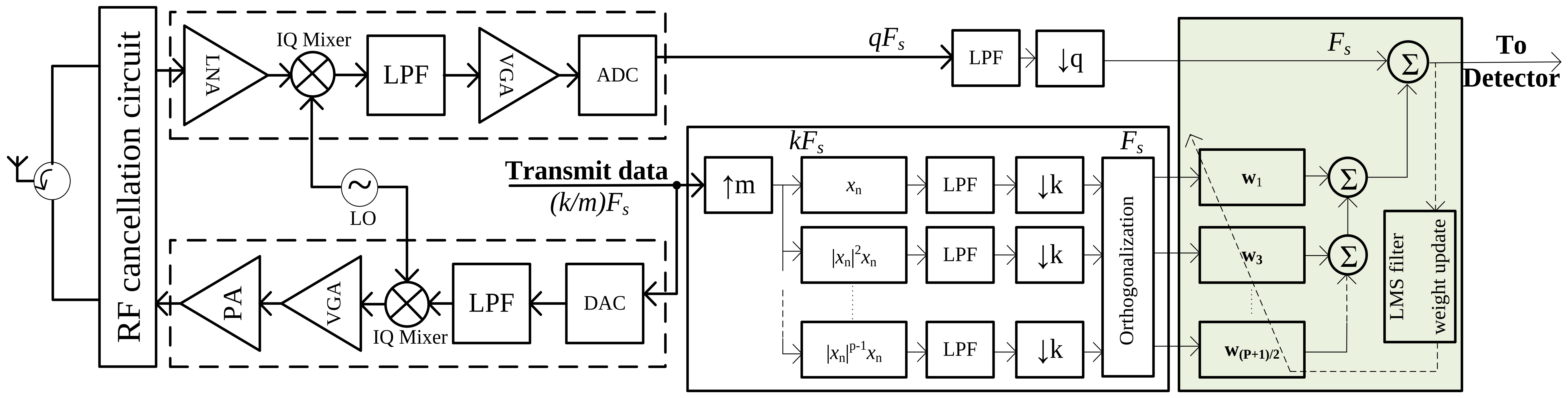
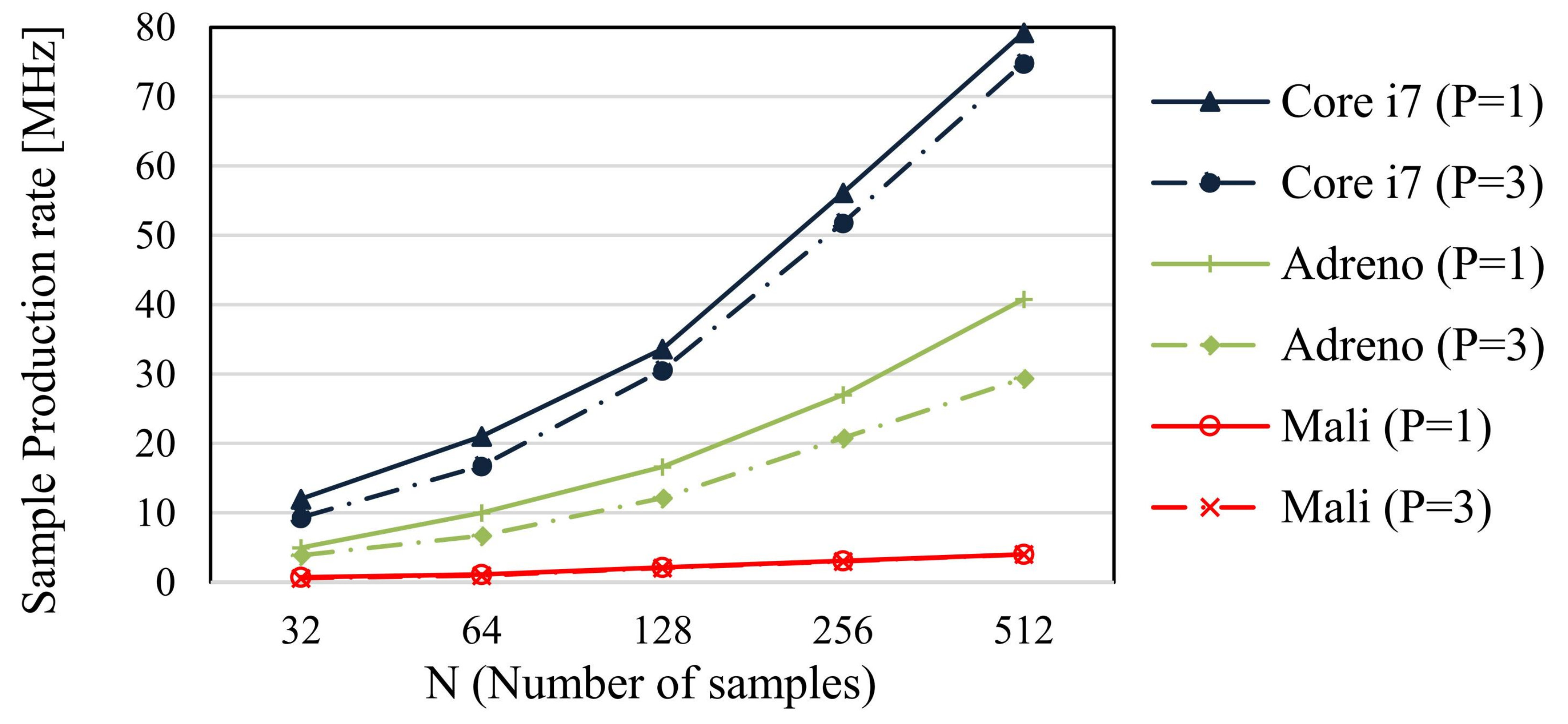


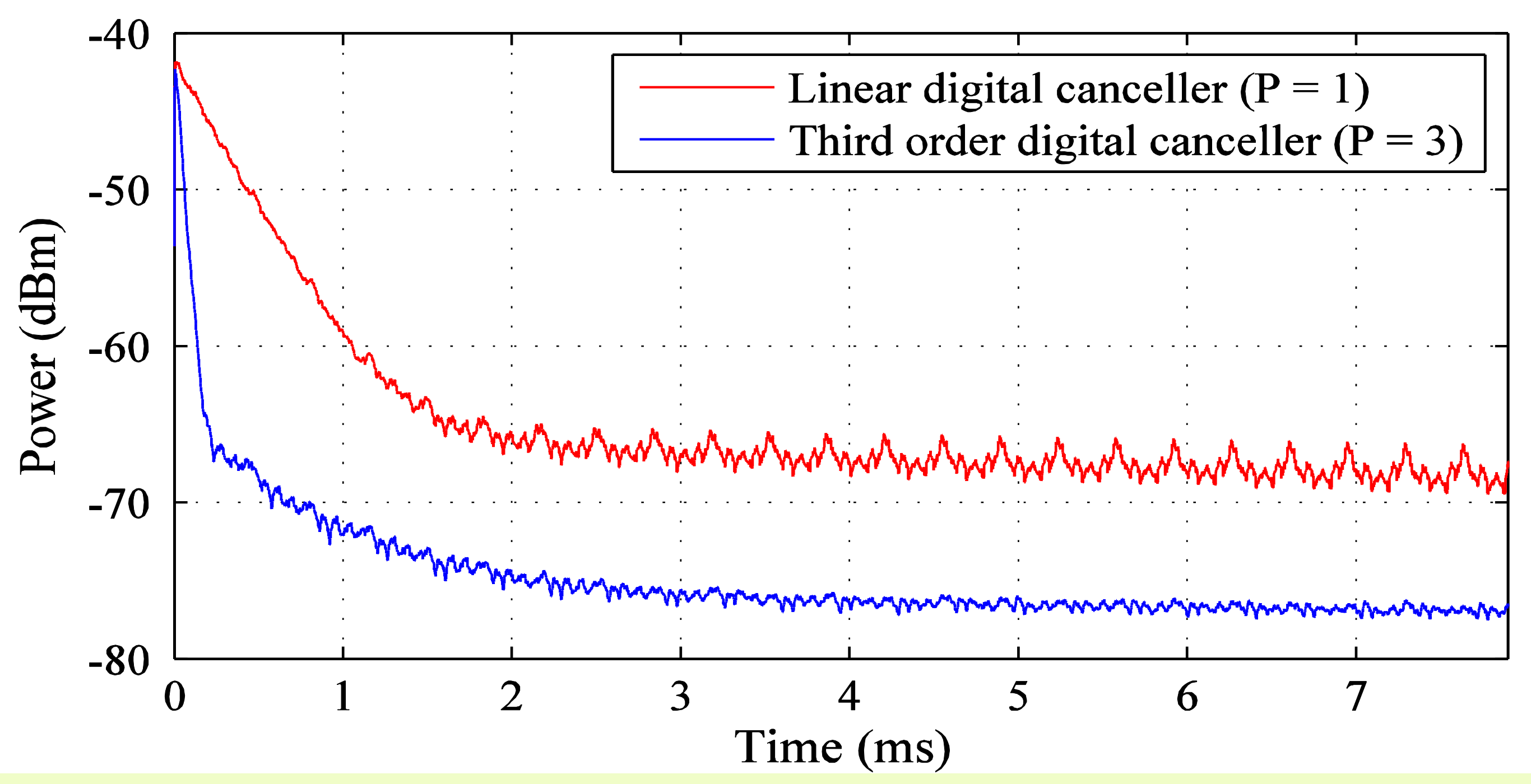
- Full-duplex systems improve spectral efficiency by transmitting and receiving **concurrently at the same frequency**.
- The most essential issue in full-duplex communications is to eliminate the strong **self-interference (SI)** signal, which results from the direct co-existence of the powerful transmit signal and the received signal of interest at the same carrier.
- Cancellation of the SI signal is a challenging task, because the transmit signal will be both linearly and nonlinearly distorted, most significantly by the **power amplifier (PA)** when coupling from TX chain to RX chain.

- To effectively mitigate the SI signal, the cancellation process is carried out in two stages, namely, **RF cancellation** and **digital cancellation.**
- Utilizing **Open Computing Language (OpenCL)** and the available **parallel resources** in **multi-core processors** and **GPU**s, this work proposes a **software implementation** for **digital SI cancellation** in full-duplex systems, applicable on **both the network side and the mobile station side**.
- In general, by introducing more parallelism, i.e., **increasing the number of samples processed in parallel** (*N*), increases the sample production rate as illustrated in the figure on the right
- *At **N** = **128***, it is possible to achieve a real-time implementation using the **Intel Core i7**, while the **Adreno 430** is capable of real-time nonlinear cancellation with ***N* = 512**.
- There is a **trade-off** between **latency** and **sample production rate**

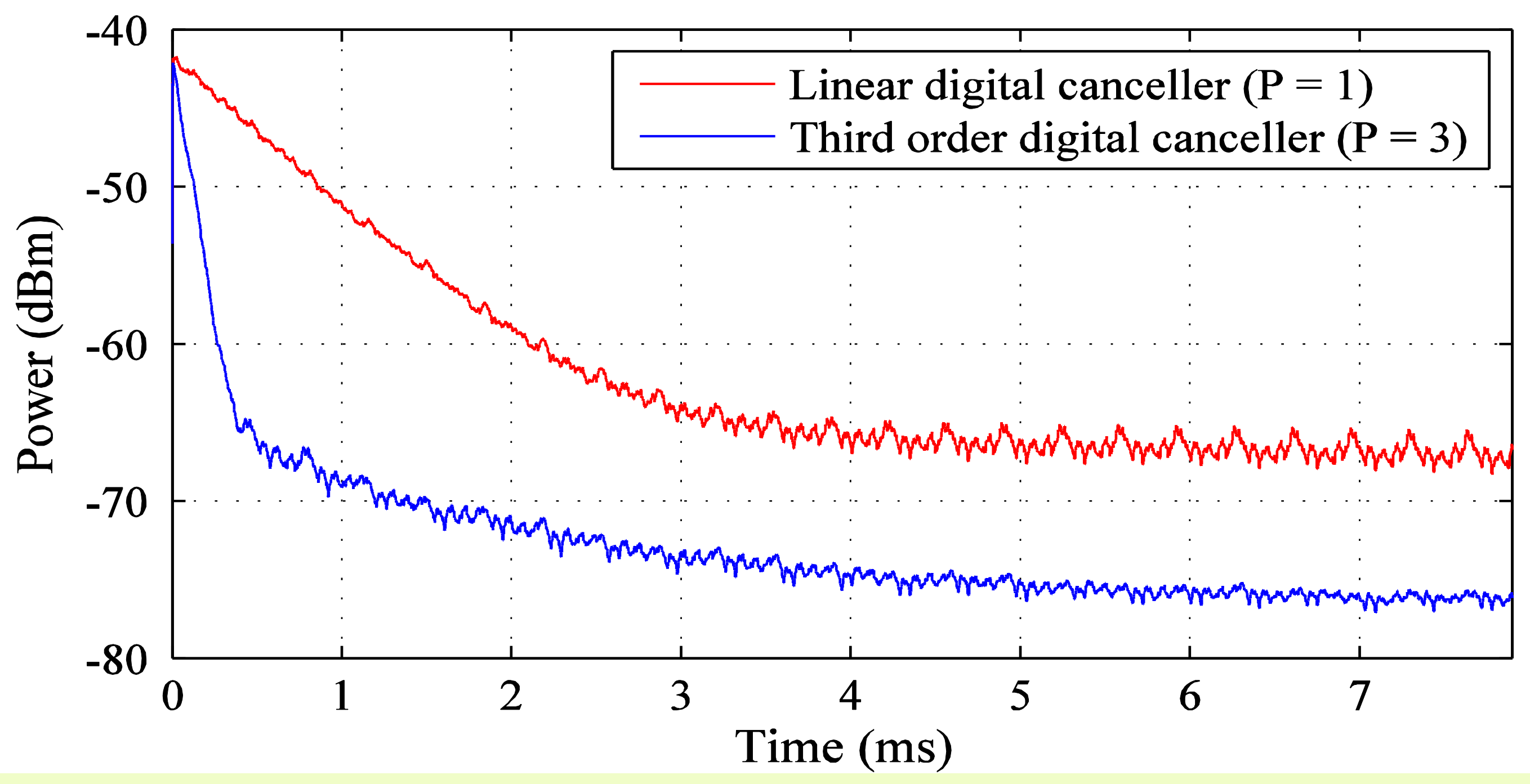
- **Adopted platforms**:
  - **Intel® Core^{TM} i7-4800MQ (a desktop CPU)**
  - **Qualcomm® Adreno^{TM} 430 (a mobile GPU)**
  - **ARM® Mali^{TM} -T628 MP6 (a mobile GPU)**



- The algorithm was executed for a set of data obtained from an **actual full-scale full-duplex radio prototype system**.
- The average power of digital canceller output signal from the software implementation on **Adreno 430**:



(a) *N* = 16



(b) *N* = 32

Conclusions:

- Utilizing the Qualcomm Adreno 430 GPU on the mobile side, and the Intel Core i7 CPU on the base station side, the cancelled signal can be produced at the required rates for real-time processing, in case of, e.g., 20 MHz cancellation bandwidth.
- Hence, it can be concluded that, using off-the-shelf mobile GPUs, a real-time implementation of the proposed LMS-based solution for adaptive nonlinear digital SI cancellation is feasible also for mobile scale full-duplex devices.

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➢ Algorithm: LMS-based adaptive nonlinear digital cancellation

```
Initialize $\boldsymbol{w}$ to 0, and $n$ to $L_{post}$
while transmitting do
    $\boldsymbol{u}(n) = \left[\tilde{\boldsymbol{u}}(n + L_{pre})^T \cdots \tilde{\boldsymbol{u}}(n - L_{post})^T\right]^T$
    $e(n) = r_x(n) - \boldsymbol{w}(n)^H \boldsymbol{u}(n)$
    $if\ (n\ mod\ N == 0)\ \boldsymbol{then}$
        $\boldsymbol{w}(n+1) \leftarrow \boldsymbol{w}(n) + \mu e^*(n)\boldsymbol{u}(n)$
    end if
    $n \leftarrow n + 1$
end while
```

- ➢ This algorithm is modified to adjust the frequency of filter weight updates. Here, $L = L_{pre} + L_{post}$ is the length of the channel filter, where L_{pre} and L_{post} represent the pre-cursor and post-cursor taps, respectively.
- ➢ *N* defines how often the filter weights are updated.
- ➢ $\tilde{\boldsymbol{u}}(n)$ contains the pre-computed orthogonalized basis functions, $r_x(n)$ is the observed signal, and $e(n)$ represents the cancelled signal.

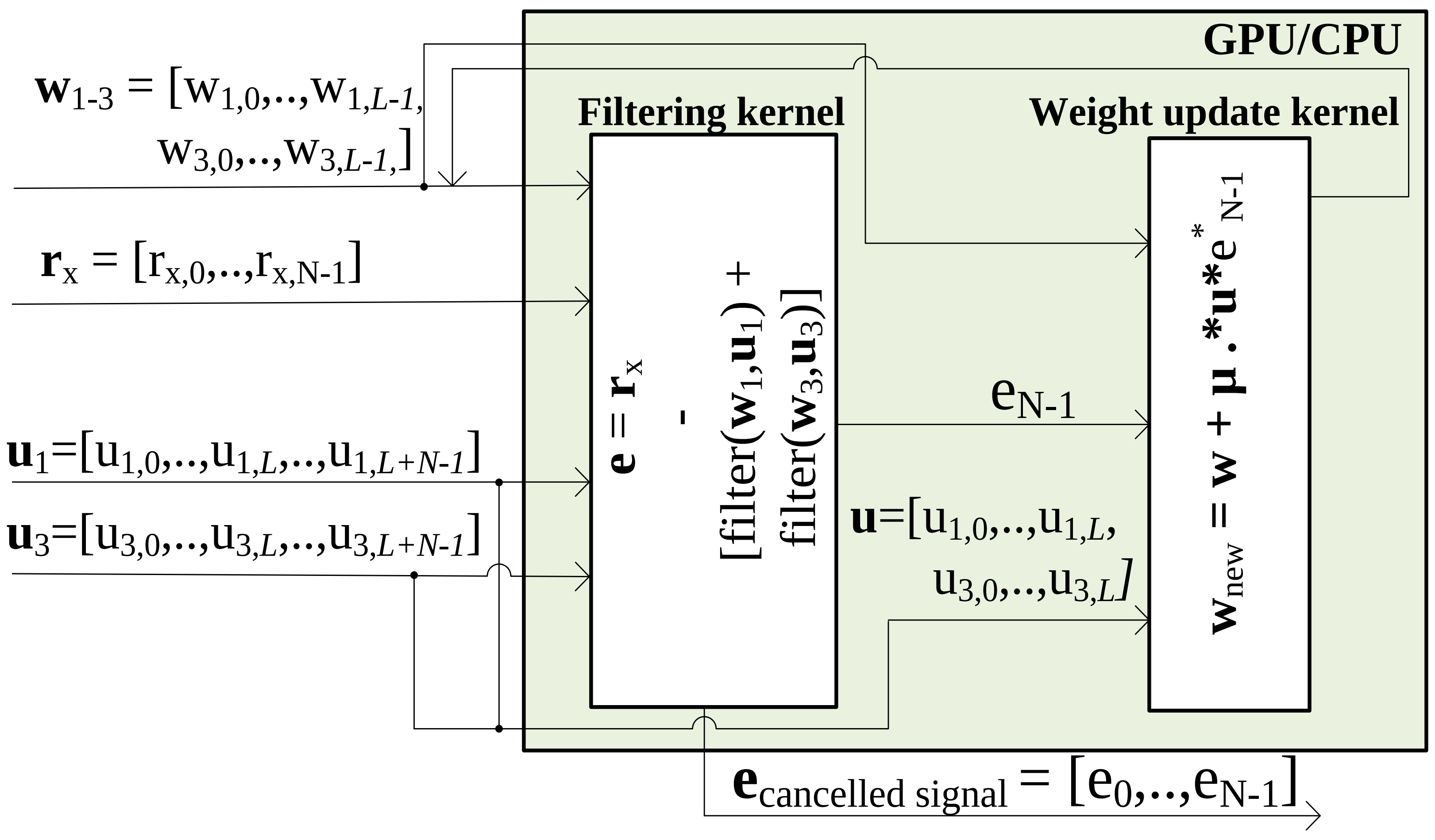
➢ Some details on the platforms:

	Core i7	Adreno 430	Mali-T628
Clock frequency	2700 MHz	600 MHz	600 MHz
Parallel PEs	64	~200	32

➢ Real-time Requirement:

- To be able to process a 20 MHz wide LTE or WiFi carrier, we assume a sample rate of F_s = 24 MHz.
- Thus to achieve real-time processing, the output signal should be produced at a 24 MHz rate, meaning that production of each output sample should take equal to or less than 41.66 ns (1/24 MHz= 41.66 ns).

➢ Digital cancellation is done using two OpenCL kernels:



- ➢ To introduce **more parallelism** to the algorithm, a **block of *N* samples** are buffered to be **processed simultaneously**.
- ➢ Execution times when ***N* = 256** for both the **linear (*P* = 1)** and third order **nonlinear (*P* = 3)** digital cancellers are shown in the table below.

	Core i7		Adreno 430		Mali-T628	
Nonlinearity order	*P*=1	*P*=3	*P*=1	*P*=3	*P*=1	*P*=3
Filtering time for *N* samples [µs]	3.04	3.42	5.88	8.70	59.61	59.88
Time for updating filter weights [µs]	1.52	1.52	3.5	3.58	23.67	24.02
Total time for *N* samples [µs]	4.56	4.94	9.4	12.28	83.28	83.90
Total time for one sample [ns]	17.81	19.29	36.64	48	325.30	327.70

- ➢ As Mali-T628 runs at a clock frequency close to Adreno’s, its slower performance can be explained by looking at the **number of parallel computing units** for the two platforms provided in the table.
- ➢ As expected, the presented results in the above table show Mali to be approximately six times (200/32 = 6.25) slower than Adreno.

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