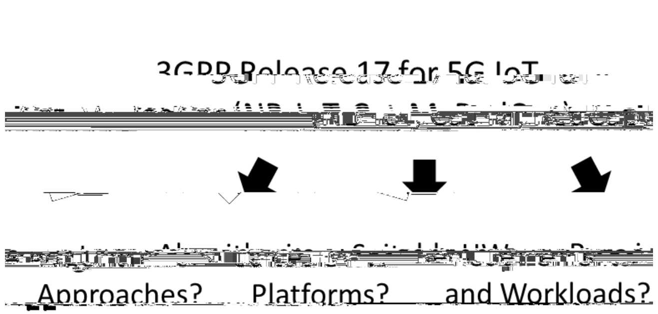

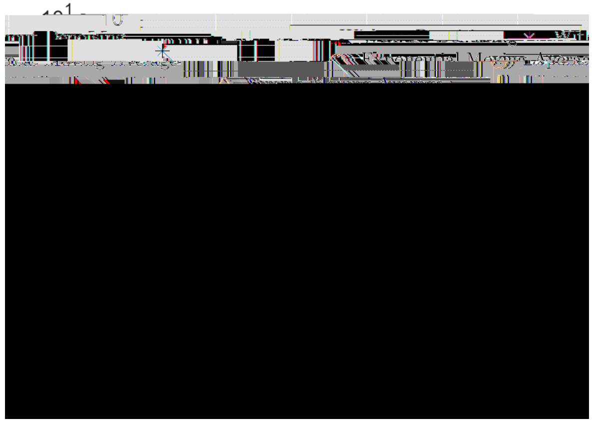

"Flexible Channel Estimation for 3GPP 5G IoT on a Vector Digital Signal Processor"

- *Generalisation of the moving average-based channel estimation and its mapping onto appropriately sized programmable platforms for 5G Release 17 IoT workloads, including the newly introduced RedCap.*
- *Identified workloads and requirements for channel estimation across all IoT specification.*
- *Devised an algorithmic approach that utilises flexibility of a programmable platform to provide robust approximate MMSE channel estimation quality using suboptimal moving average variants suitable for IoT, based on the best MSE performance criteria algorithm switching.*
- *Designed, implemented and measured denoising subkernels and the complete 5G IoT compatible channel estimation on 3 platforms, 32-bit RISC reference, vDSP128 and vDSP512 to cost effectively support IoT workloads.*
- *Processor SIMD architecture recommendation for each of the specified standards.*

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VODAFONE CHAIR

Motivation: Introduction of RedCap for 3GPP 5G IoT

- NR Reduced Capability (RedCap/REDCAP/NR-Lite/NR-Light) to cover applications in the m[redacted] 7 n T 1 0 .

3GPP Release 17 for 5G IoT
(NB-IoT, Cat-M, RedCap)

Requirements and Workloads?

Algorithmic Approaches?

Suitable HW Platforms?

Workload, Platforms, Algorithms

Algorithmic Optimisation and 32-bit RISC Implementation

Further Algorithmic Optimisations:

- *SMA – i) mpy instead of div ii) discussion on less cycles of mac vs more cycles of add*
- *EMA – i) β instead of $(1-\alpha)$*

SMA

$$\tilde{H}(k,l) = \frac{1}{N_1 + N_2 + 1} \sum_{i=l-N_1}^{l+N_2} \hat{H}(k,i).$$

$$\tilde{H}(k,l) = g \sum_{i=-N_1}^{N_2} \hat{H}(k,l+i) = \sum_{i=-N_1}^{N_2} g \cdot \hat{H}(k,l+i),$$

EMA

$$\tilde{H}(k,l) = \alpha \hat{H}(k,l) + (1-\alpha)\tilde{H}(k,l-1),$$

$$\tilde{H}(k,l) = \alpha \hat{H}(k,l) + \beta \tilde{H}(k,l-1),$$

Pseudo Code of Optimised Equations:

Algorithm 1: Moving Average in the SMA Form

```
input  : Channel measurement Ĥ and filter coeffic[illegible]
output : Filtered channel measurement
         tildeH
// Data register v1
// ACC register w1
for l ← 0 to L − 1 do
    for k ← 0 to K − 1 do
        [illegible]
        ...
    end
    [illegible]
    ...
    end
end
```

Algorithm 2: Moving Average in the EMA Form

```
input  : Channel measurement Ĥ and filter coefficients α, β
output : Filtered channel measurement H̃
// Data register v1
// ACC register w1
v1 = 0;
for k ← 0 to K − 1 do
[illegible]
```

[redacted]

Operations [1/ms]:

- *See TABLE IV (352x more than prior art Cat-M)*

TABLE IV
NUMBER OF OPERATIONS.

Workload	Pilots [1/ms]	Operations [1/ms] SMA	Operations [1/ms] EMA	Filtering Axis
[illegible]	[illegible]	[illegible]	[illegible]	one axis
NB-IoT	4	24	8	only t
Cat-M	12	72	24	only t
FR1 RedCap	424	5088 (70.7 × 72)	1696	both t+f
FR2 RedCap	2112	25344 (352 × 72)	8448	both t+f

32-bit reference Implementation:

- *Cycles [1/ms] -> Frequency [kHz]*
- *i) 25 MHz for just FR2 RedCap denoising is unacceptable, a SIMD solution is needed. ii) NB-IoT OK.*
- *Ops/cycles go up with higher workloads due to relatively smaller loop overhead and pipeline depth impact*

TABLE V
32-BIT SCALAR REFERENCE: REQUIRED CLOCK FREQUENCY AND MAC UNIT UTILISATION.

Workload	Frequency [kHz]		Operations/Cycles [%]	
	SMA	EMA	SMA	EMA
NB-IoT	[illegible]	[illegible]	[illegible]	[illegible]
Cat-M	[illegible]	[illegible]	[illegible]	[illegible]
FR1 RedCap	[illegible]	[illegible]	[illegible]	[illegible]
FR2 RedCap	[illegible]	[illegible]	[illegible]	[illegible]

Results: Key Contributions

Algorithm:

- *Moving Average filter variations offer good MSE performance and low computational cost – good for IoT*
- *MSE performance near optimal (MMSE) with SW alg. switching*
- *SW Switching is easy on a flexible, programmable platforms*

Algorithm	Moving Average based Channel Estimation					
Architecture	**32-bit scalar**		**vDSP128**		**vDSP512**	
Metric	Req. Clock [MHz]	Arithmetic Ops/Cycles [%]	Req. Clock [MHz]	SIMD Efficiency [%]	Req. Clock [MHz]	SIMD Efficiency [%]
NB-IoT	**0.25**	**89**	0.08	67	0.04	33
Cat-M	**1.28**	**97.8**	**0.34**	**92**	0.11	74
FR1 RedCap	25.9	99.89	**6.5**	**99.48**	**1.65**	**97.9**
FR2 RedCap	128.9	99.98	32.4	99.89	**8.09**	**99.58**

Standard	NB-IoT	Cat-M	FR1 RedCap	FR2 RedCap
Suitable Architecture	**32-bit**	**32-bit to 128-bit**	**128-bit to 512-bit**	**512-bit**