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CEVA TECHNOLOGY
SYMPOSIUM SERIES

12th YEAR

Cost and power sensitive cellular connectivity solution for IoT devices with CEVA-Dragonfly NB2

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NB-IoT for The Massive Internet of Things

Cellular IoT

Massive MTC

Cat-M2 R14	Cat-M1 R13	Cat-NB2 R14 – Cat-NB1 R13
FeMTC	eMTC	eNB-IoT - NB-IoT
3Mbps	1Mbps	160Kbps - 60Kbps

Voice enabled Wearables

Remote Surveillance

Connected Cars

Wearables

Smart Utilities

Healthcare

Asset Tracking

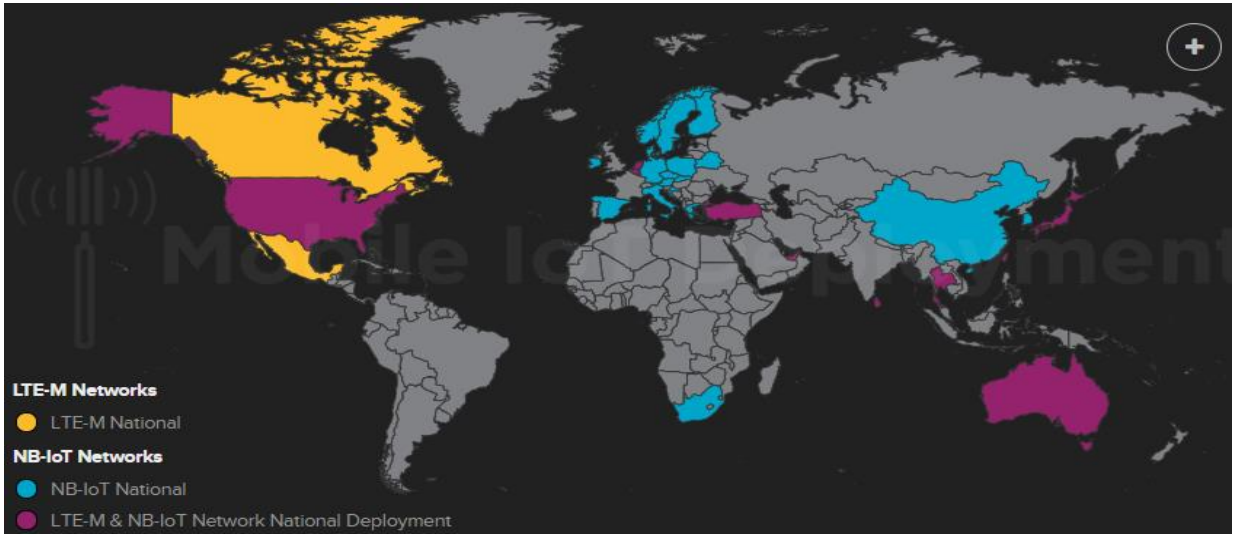
Smart Infrastructure

Environmental Monitoring

Smart Cities

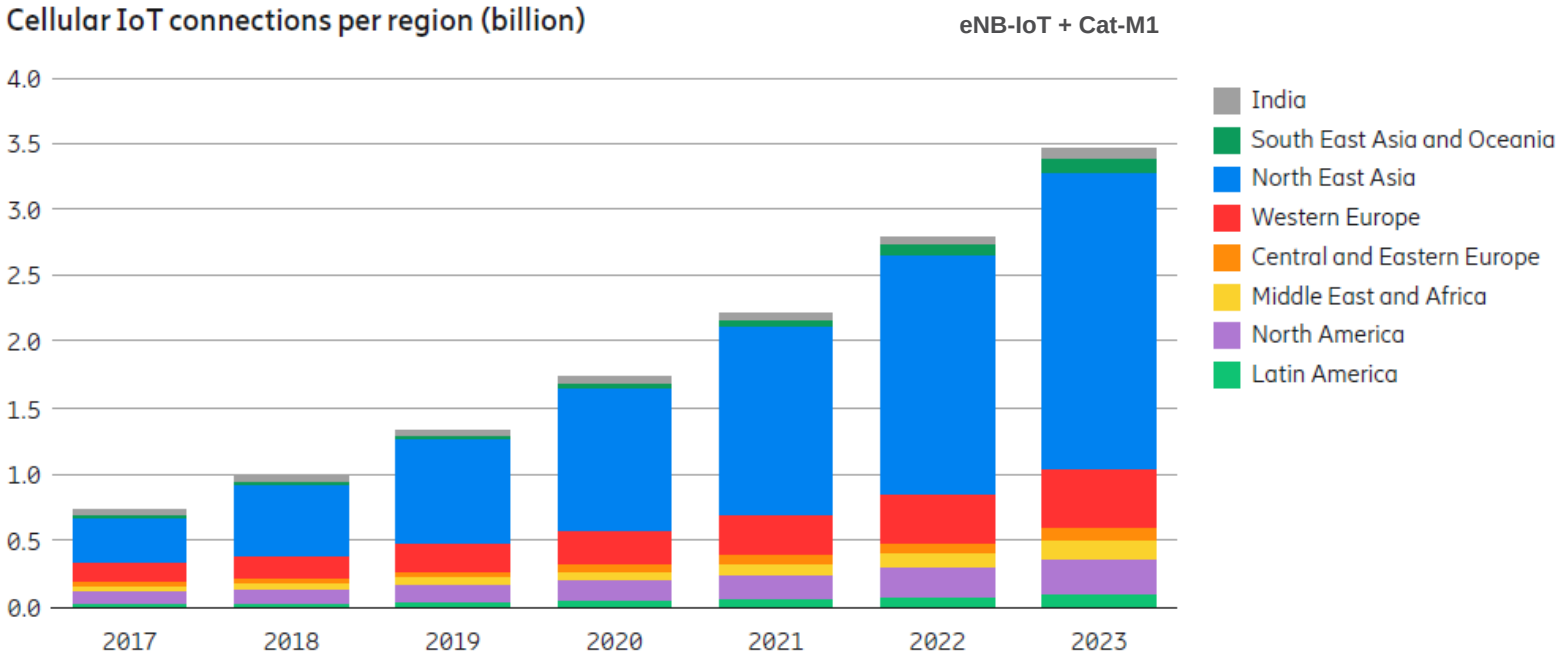
Cellular IoT Network Deployments

- Commercial Mobile IoT networks are being rolled out around the world with a total of **60 launches by 33 operators in 34 countries** as of September 2018
- NB-IoT represents 80% of all deployments
- AT&T and Verizon announced NB-IoT deployment plans for 2019, on top of their current Cat-M networks



Cellular IoT Market Forecast

30% CAGR between 2017 and 2023



Source: Ericsson Mobility Report June 2018

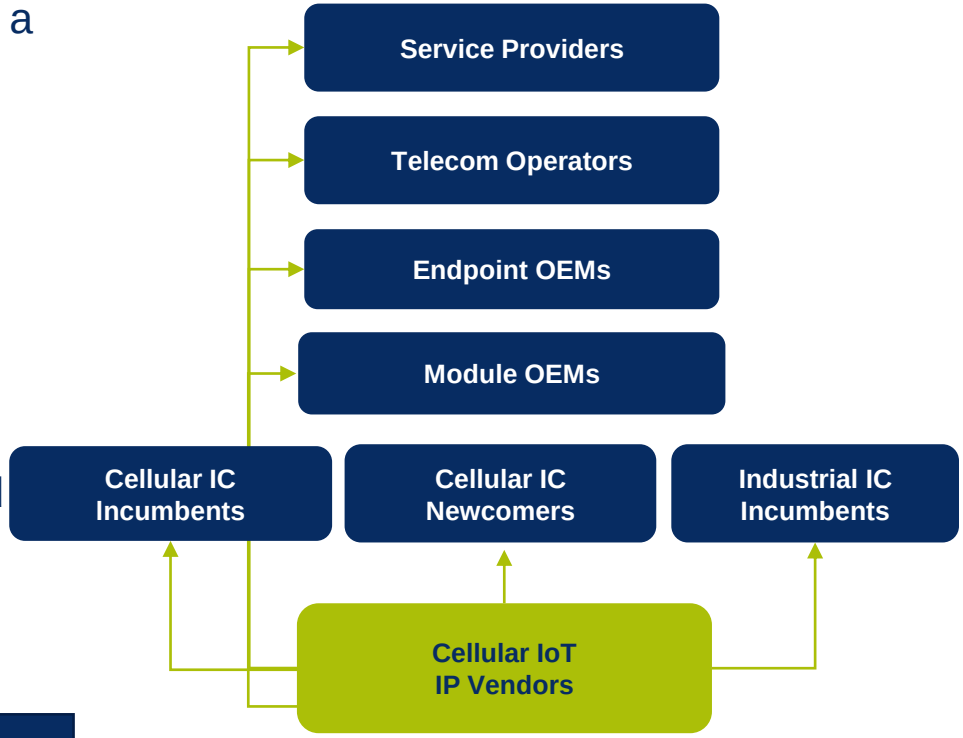
NB-IoT Market Trends

- Ericsson recently doubled its forecast for cellular IoT. Huge deployments are underway in China and soon India
- The volumes of chips, pricing models etc are causing upheaval in the supply chain – chip makers becoming module makers, module makers becoming chip makers, operators and OEMs looking to develop their own custom silicon
- Dozens of companies who have no previous cellular experience looking to enter this market and require a lot of help to develop custom devices and endpoints at the right cost
- NB-IoT being deployed in high volume by end of this year

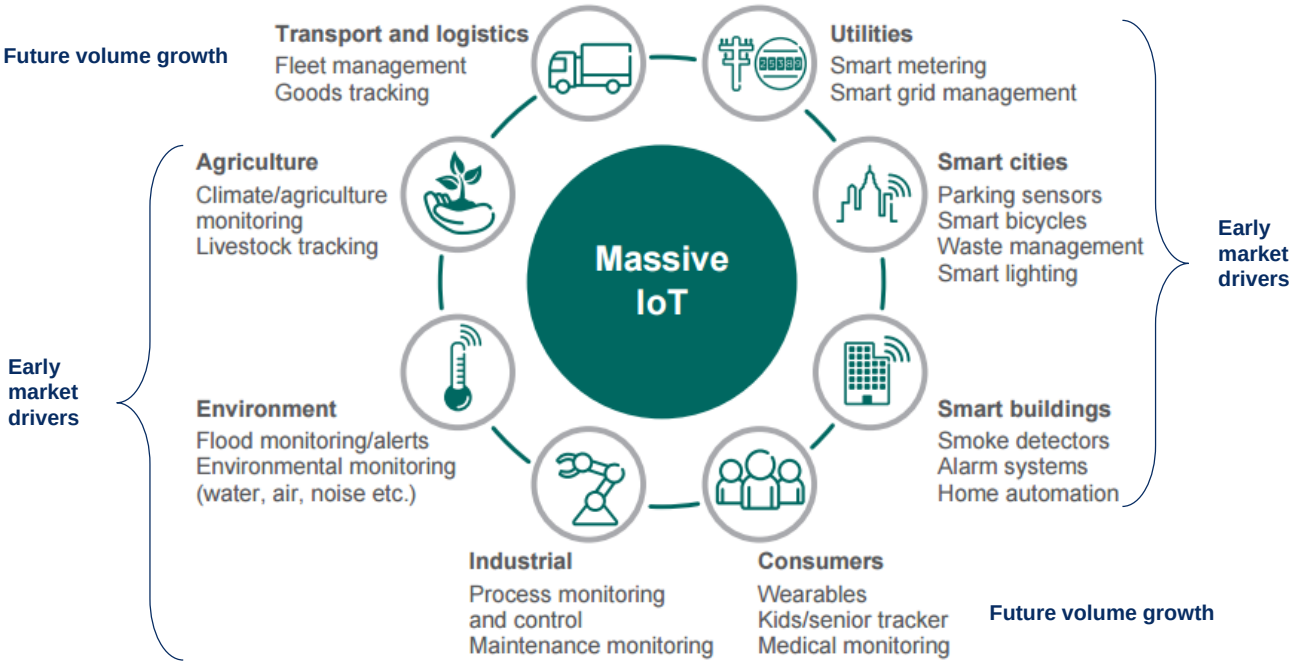
Disruption of Cellular IoT Value Chain

- OEMs and service providers need to reach a $4-5 endpoint BOM which requires a $1.5 single SoC solution (includes modem, GNSS, AP, sensor)
- New entrants, without cellular expertise, must cut stacked margins and define their own SoC to maintain differentiation and achieve single chip application integration
- IP vendors provide NB-IoT IP solutions and chip design help
- Fully integrated NB-IoT IP solutions lower entry barriers by reducing risk and TTM

Cellular IoT IP vendors are working with the entire value chain



NB-IoT Market Segments



50% of all use cases will require a combination of NB-IoT with indoor and/or outdoor positioning even for fixed devices (locate sensor)

Cellular IoT Categories

Cellular IoT Categories	Cat-1 (Rel. 8)	Cat-M1 eMTC (Rel. 13)	Cat-M2 FeMTC (Rel. 14)	Cat-NB1 NB-IoT (Rel. 13)	Cat-NB2 eNB-IoT (Rel. 14)
Downlink peak rate	10 Mbps	1 Mbps	4 Mbps	~30 Kbps	~142 Kbps
Uplink Peak rate	5 Mbps	1 Mbps	~7 Mbps	~60 Kbps	~126 Kbps
UE receiver BW	20 MHz	1.4 MHz	5 MHz	180 KHz	180 KHz
UE TX Power Class	23 dBm	20/23 dBm	20/23 dBm	20/23 dBm	14/20/23 dBm
Duplex mode	Full/Half duplex FDD / TDD	Full/Half duplex FDD / TDD	Full/Half duplex FDD/TDD	Half duplex	Half duplex
Number of DL Ant.	2	1	1	1	1

- Lower bandwidth and single DL antenna reduces RF Front-end BOM
- New power class of 20 and 14 dBm Tx power allow same die integration of CMOS RF & PA
- Half Duplex reduces RF Front-end BOM (no SAW filter, no diplexer, single osc)

What is NB-IoT bringing to the market?

- Compared to other LPWA technology (LoRa, Sigfox), NB-IoT offers
  - Guaranteed quality of service offered by licensed bands rather than unlicensed
  - True bi-directional communication that is required for in field over the air application upgrade
  - Deterministic latency and higher data-rate

NB-IoT	✓
LoRa	✗
sigfox	✗

- Compared to Cat-M, NB-IoT offers
  - Dual mode Cat-M/NB-IoT chips cannot offer the price point required by Service Providers and Opertators,
  - Single mode NB-IoT chips cost half and consume a third of Cat-M chips
  - Lower subscription and new bulk pricing (fleet, data combo)

NB-IoT	✓
LTE Cat M1	✗

CEVA-Dragonfly NB2 Introduction

First World-Wide eNB-IoT IP Solution – Silicon Proven

- Second Generation after wide success of Dragonfly NB1
- Fully integrated solution compliant with 3GPP Release 14
- State-of-the-art world-wide RF design implemented in 55nm and 40nm processes
- Intelligent sleep mechanisms ensure ultra-low sleep power consumption of a few microAmps
- Optimized multi-constellation GNSS package includes RF, DFE and new instructions to boost performance by a factor of **8**
- One stop shop IP solution license as a whole system or as a subset

Dragonfly NB2 lowers entry barriers and ensures lowest bill of materials of eNB-IoT endpoints

CEVA-Dragonfly NB2 IP in a Nutshell

Complete NB-IoT IP ready for SoC Integration

Hardware

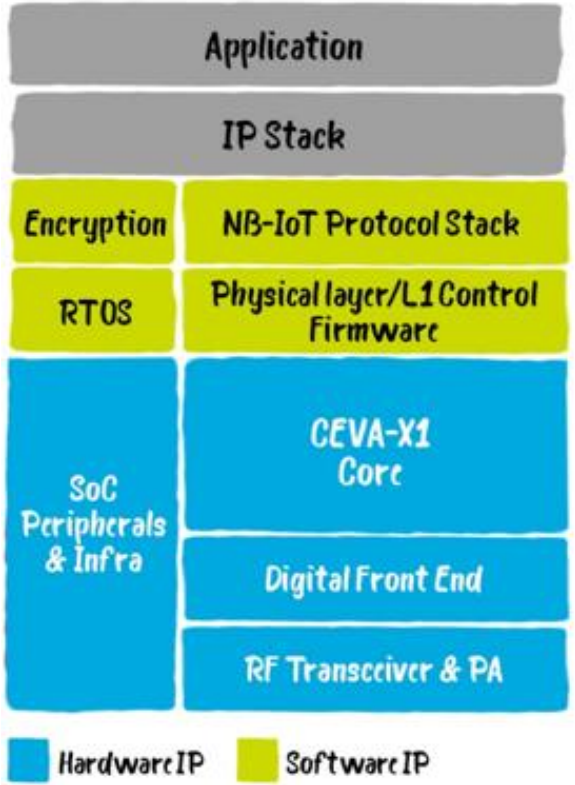
- CEVA-X1 processor
  - Core+MSS
  - NB-IoT Xtend Package
  - GNSS Xtend Package (WIP)
- Digital Front-End RTL
  - NB-IoT
  - GNSS (WIP)
- CEVA-DGF Subsystem Platform
  - RTL (peripherals and connectivity)
  - RTL Simulation
- Embedded NB-IoT RF transceiver
  - Black box (GDS2) or White box (process specific)
  - Optional dual-mode GNSS

Software

- Firmware Source code
  - NB-IoT Protocol Stack
  - Layer 1
  - freeRTOS (based open source)
  - Platform drivers
- Low Level Reference Libraries
  - DSP libraries
  - NB-IoT Libraries

Platform

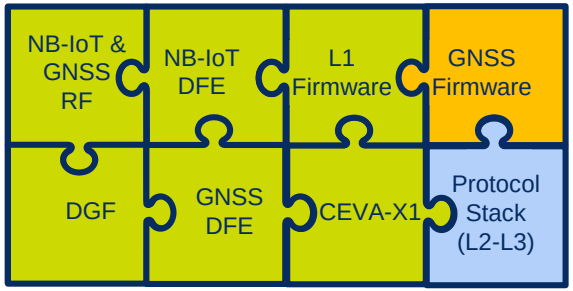
- NB-IoT EVB
  - RF + Baseband



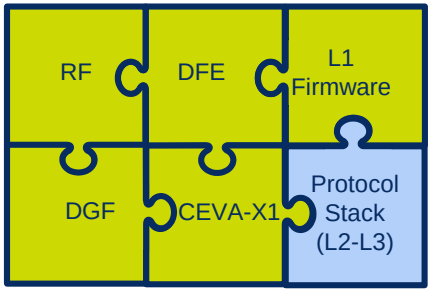
NB-IoT & GNSS IP Licensing Options

CEVA IP | Customer or 3rd party | Protocol Partner | GMV Partner

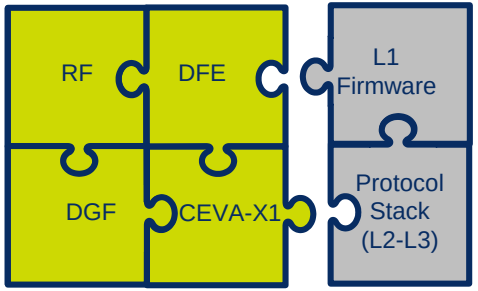
Complete NB-IoT & GNSS HW & SW Solution

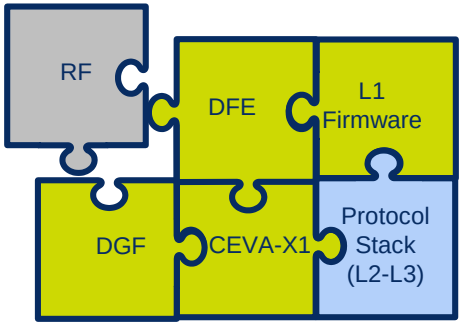


Complete HW & SW Solution



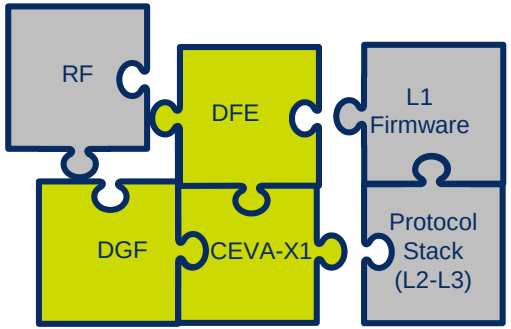
Hardware only





Third party RF

Customer does RF Integration with L1 FW & DFE



Third party RF & L1-L2-L3

Customer does RF Integration with DFE

Dragonfly NB2 Main 3GPP Features

- Release 14, category-NB2 Half-Duplex FDD
  - Data rates
    - Uplink ~126Kbps
    - Downlink ~146Kbps
- UE support single RX and TX antenna
- Supporting all operation modes
  - In-band, Guard-band and standalone
- Coverage enhanced – 20 dB coverage extension
- Single-tone and multi-tone uplink transmission
- Control plane and/or User plane CIoT EPS optimization
- Power saving
  - Extended IDLE mode DRX supporting up to ~3 hr cycle
  - Connected mode DRX up to 10.24 sec cycle
  - PSM

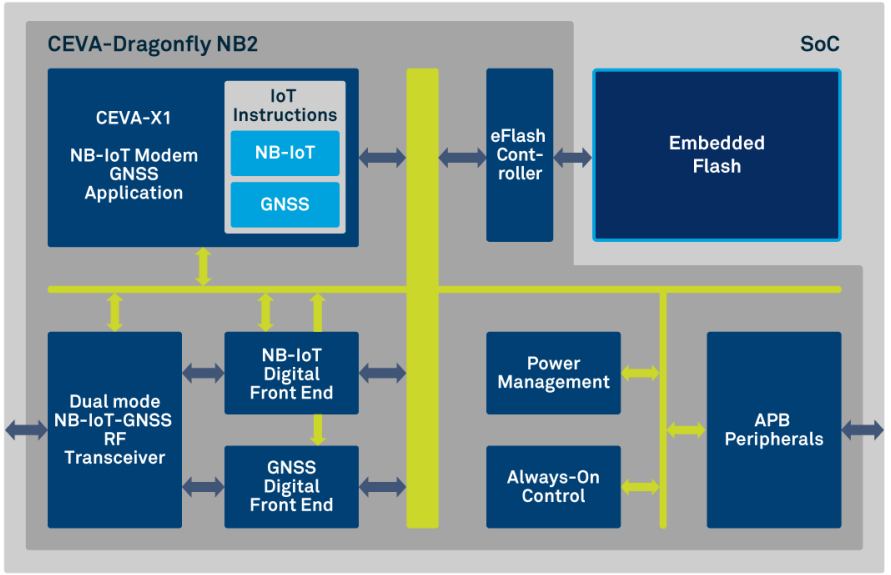
Release14 Cat-NB1 vs Cat-NB2

Parameters	Category-NB1	Category-NB2
Duplex Mode	Half-Duplex FDD	
Channel Bandwidth	180 kHz	
Antenna Scheme	Single Rx and Tx antenna	
Downlink allocation	1 PRB	
Data Transmission scheme	Single Tx antenna or SFBC (Using up to 4 Tx antennas)	
Control channel	NPDCCH	
Uplink allocation	1 PRBs, single & multi tone 15Khz & 3.75kHz spacing	
DL Modulation	QPSK	
UL Modulation	BPSK, QPSK	
Number of HARQ processes	1	1 / 2
UL/DL TB Size	UL 1000 Bits / DL 680 Bits	UL 2536 Bits / DL 2536 Bits
Uplink Maximum power	20 / 23 dBm	14 / 20 / 23 dBm
Positioning	No	OTDOA
Enhanced Coverage	Supported	

Asset Tracker SoC architecture

Dual mode eNB-IoT and GNSS

- Single processor architecture
  - SW based eNB-IoT & GNSS modems
- No need for GNSS receiver HWA
- Dual mode RF Transceiver
  - with NB-IoT and GNSS DFEs
- Multi-constellation GNSS
  - Dynamically change constellation via SW
- SW tasks are time multiplexed
  - Application
  - GNSS location tracking
  - eNB-IoT



CEVA-Dragonfly NB2 IP Highlights

- Fully integrated IP enables fast time to market with no risk
  - Complete eNB-IoT RF Transceiver and PMU
  - Complete modem SW (L1-2-3) integrated on HW
  - Program cache supports embedded Flash
  - Dedicated NB-IoT instruction extensions reduce power
- Single core solution enables ultra-low cost IoT devices
- Small area, small foot print, low power design

- 2nd gen IP support multi-constellation asset tracking
  - Dual-mode eNB-IoT and GNSS RF Transceiver
  - GPS and Beidou constellation support
  - Dedicated GNNS DFE
  - Dedicated GNSS instruction extensions
- State of the art algorithms improve modem performance
- Modem, GNSS and application software updates over the air (OTA)

Feature Summary - Dragonfly NB2 vs NB1

Features	Dragonfly NB2	Dragonfly NB1
3GPP Release	Rel.14	Rel.13
UE Category	Cat-NB2	Cat-NB1
Reference silicon	55 & 40nm	55nm
USIM & eSIM interfaces	Yes	No
Low power always on for deep sleep	Yes	No
Embedded Flash support	Yes	No
NB-IoT Digital Front End	Rel.14	Rel.13
NB-IoT instruction extensions	Rel.14	Rel.13
GNSS RF Receiver	Yes	No
GNSS Digital Front End	Yes	No
GNSS instruction extensions	Yes	No
ClearVox for voice & sound sensing	Yes	No

CEVA-Dragonfly NB2 Components

1 CEVA-X1

- Combines CPU and DSP instruction set and features
- 4-way VLIW/SIMD architecture
- 2x 16x16 or 1x 32x32 MAC
- High bandwidth memory access
- Parallel 64-bit load & store
- CoreMark/MHz: 3.6
- Dynamic branch prediction
- Byte support for control code
- Optional program and data cache
- Optional IEEE floating point
- NB-IoT instruction extensions

2 Physical Layer SW

- Cat-NB2 Rel.14 compliant
- Type-B half-duplex FDD
- Maximum UL/DL transport block size of 2536 bits
- Support 2 HARQ processes
- Support for Enhanced Coverage mode
- Support for Extended DRX
- Efficient signal processing and state of the art algorithms

3 Protocol Stack

- Cat-NB2 Rel.14 compliant
- Optimized protocol stack software for CEVA-X1
- Control and User Plane CIOT EPS optimization
- IP and Non IP data transfer modes
- Security algorithms
  - AES128, Snow3G, ZUC
- PSM - power saving mode
- RoHC - robust header compression

Dragonfly-NB2 Components

4 RF Transceiver

- Available in 55nn and 40nm
- Multi-band RF support
- Power Class 5 (20dbm) with on-chip PA
- High performance Low-IF receiver
- Embedded LNA, Switch, DC-DC, DCXO, ADC, DAC

5 GNSS

- Optional GPS/Beidou multi-constellation RF Receiver
- GNSS Digital Frontend hardware
- Dedicated GNSS instructions on CEVA-X1
- GNSS software provided by third party

6 Voice/Sound

- Voice front-end SW package runs on CEVA-X1
- ClearVox voice processing
  - SW Voice Activity Detection
  - Multi-mic beamforming
  - Noise suppression
- Always-on voice trigger
- Voice commands
- Sound sensing

CEVA-X Family at a Glance

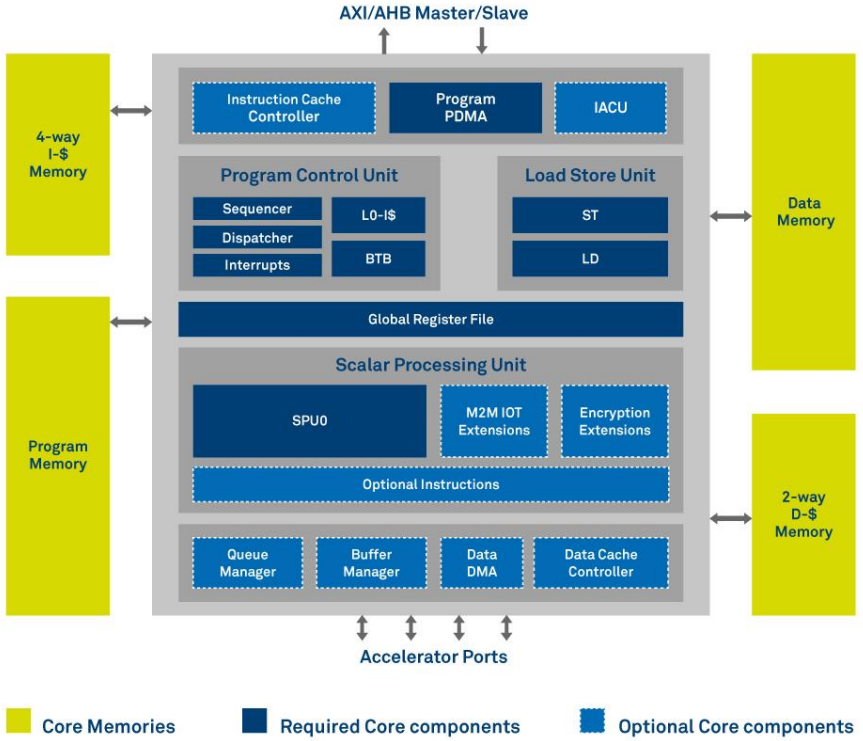
Features	X1	X2	X4
VLIW	4 way	5 way	7 way
SIMD Capabilities	32-bit	64-bit	128-bit
Scalar Units	1	2	4
MAC [16x16-bit], [32x32-bit]	2,1	4,2	8,4
Floating-Point	Optional	Optional	Optional
Data Memory width [bit]	64 LD + 64 ST	128 LD + 128 ST	256 LD + 256 ST
Fetch Line	128-bit	128-bit	256-bit
Branch Target Buffer	✓	✓	✓
Data Cache	Optional	Optional	Optional
Instruction Cache	Optional	Optional	Optional
CEVA Connect	Optional	Optional	Optional
Customized ISA (Xtend)	Optional	Optional	Optional
ISA Architecture	Shared	Shared	Shared

CEVA-X1 is designed to address cellular IoT challenges

CEVA-X1 Processor For Cellular IoT

Key Features
4-Way VLIW SIMD Processor
Dual MAC 16x16-bit; Single MAC 32x32-bit
Data Memory width 64bit load in parallel to 64 store
Branch Target Buffer – Dynamic Brunch Prediction
Configurable D-TCM and P-TCM
Support Both AXI or AHB
Efficient Instruction and Data Cache
Cellular IOT & Encryption ISA extensions
GNSS ISA extensions **New**

Winner in the China Electronic Market (CEM) 2017 Editor's Choice Awards as The most competitive MCU and DSP product in China



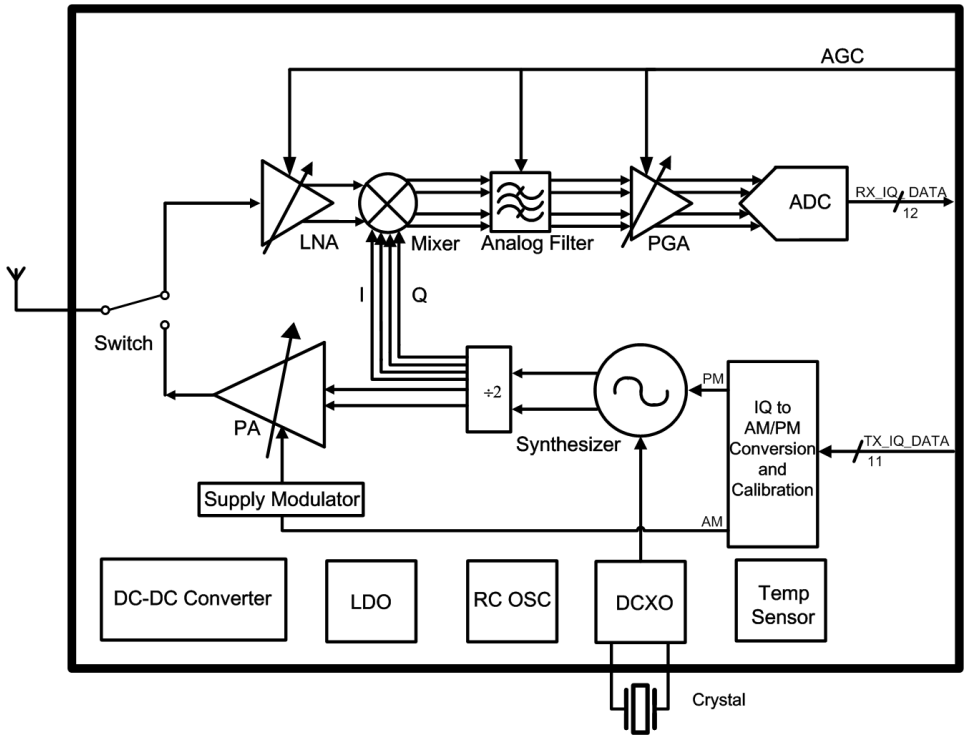
Power optimized Cellular & GNSS ISA make this processor unique for NB-IoT use cases

Dedicated M2M & GNSS Instructions

- Dedicated instructions are more power and area efficient than HW accelerators for low data-rate cellular IoT
- GNSS acquisition and tracking tasks benefit greatly from dedicated instructions to support most soft GNSS 3rd party receivers
- Dedicated instructions reduce significantly power and area and make full use of CEVA-X1 VLIW & SIMD architecture

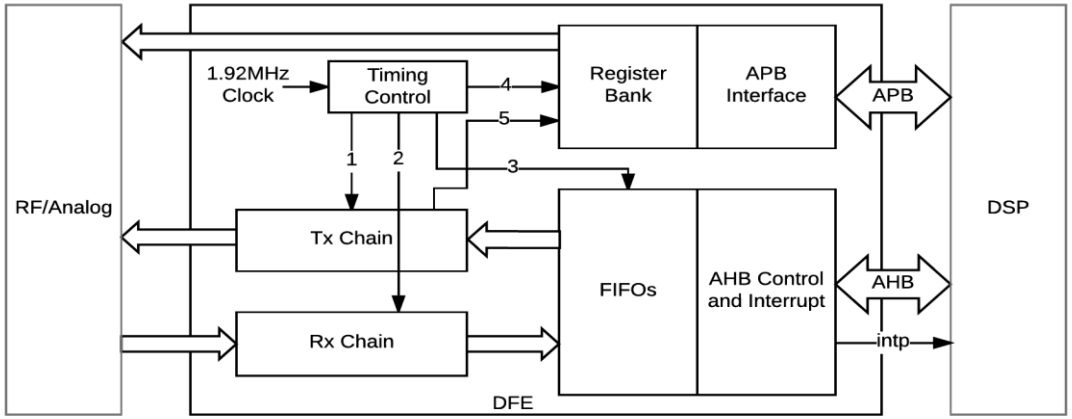
Dedicated instructions reduce MIPS & Power up to 8X for the most compute intensive Modem and GNSS tasks

RF Transceiver Architecture



- ❖High performance low-IF receiver
- ❖High power efficiency polar transmitter
- ❖On-chip DC-DC converter
- ❖On-chip power amplifier
- ❖On-chip DCXO to replace expensive on-board VC-TCXO
- ❖Digital interface to baseband

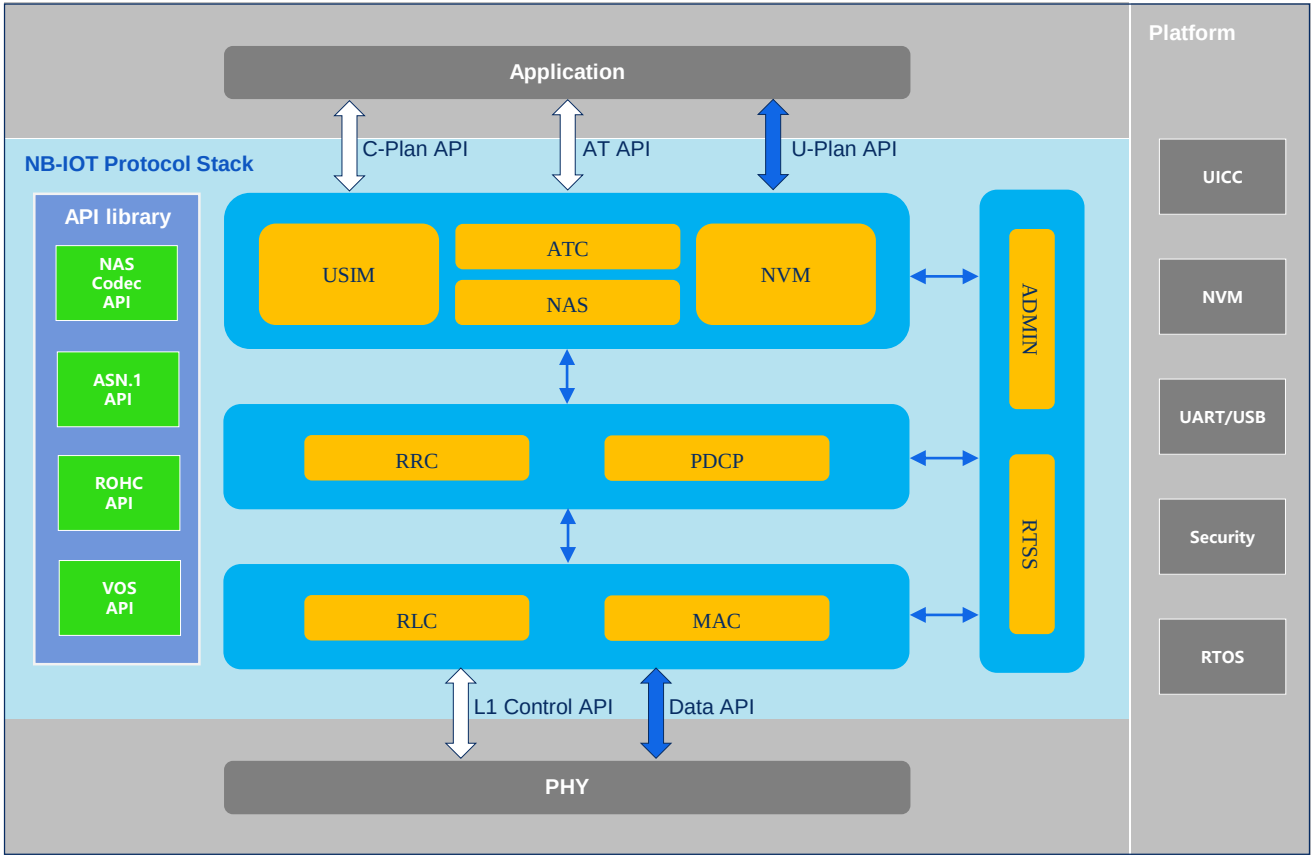
Digital Front-End (DFE) Architecture



1. Trigger for starting transmission
2. Downsampling control (subframe boundary and offset value to be adjusted)
3. AHB and FIFO control (subframe boundary and subframe index)
4. Register update (subframe boundary)/trigger for updating Tx analog registers
5. Tx done to update Tx analog registers

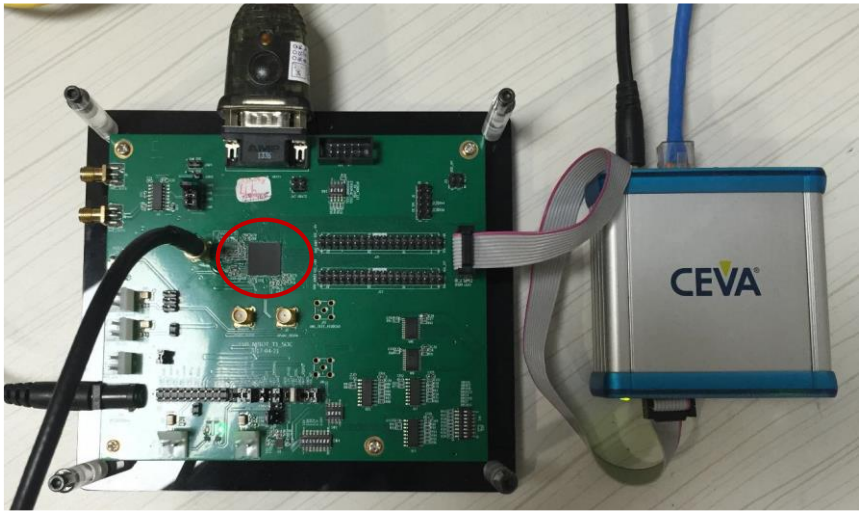
- ✓ **Time Control Unit**: Keep synchronization with eNodeB; down-sample control; FIFO control; synchronized register update; Tx time control and etc.
- ✓ **AHB Controller:** Move data from DFE FIFO to DSP internal data memory as AHB master and generate interrupt to DSP when data for one entire sub-frame is moved
- ✓ **Register band**: accessed by DSP through APB bus and take affect in synchronization manner
- ✓ **Rx Chain and Tx Chain**: Digital front end processing including up/down sampling, filtering and compensation, frequency shifting etc.

NB-IoT Protocol Stack Design



NB-IoT Development Kit

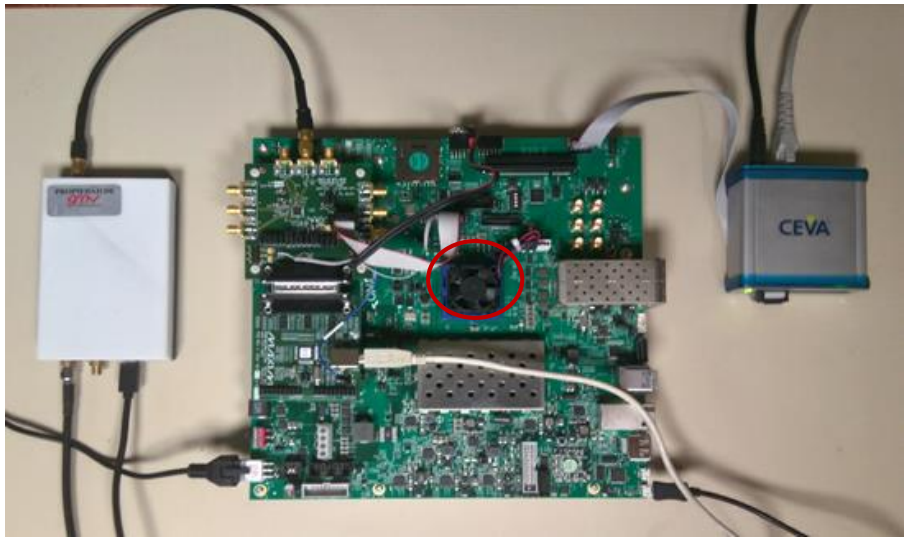
- **Key Features**
  - Development board with
    - Single die Baseband+RF chip
    - CEVA-X1 Processor
    - Peripherals: UART, SPI, GPIO...
  - DEBUG: JTAG, UART (RTSS)
  - SW Development Tools (SDT)
  - Documentation



Silicon Development Kit reduces significantly TTM and customer risk!

GNSS Development Kit

- GPS Software from GMV
- Dragonfly NB2 based on FPGA



- Position fix of person walking, once per minute

Thank You

Zeev Kaplan, CEVA

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