vivo

3GPP TSG RAN Rel-18 workshop RWS-210168

Electronic Meeting, June 28 – July 2, 2021

Motivation for new study item on ultra-low power wake up signal in Rel-18

Source: vivo, Spreadtrum communications, Guangdong Genius

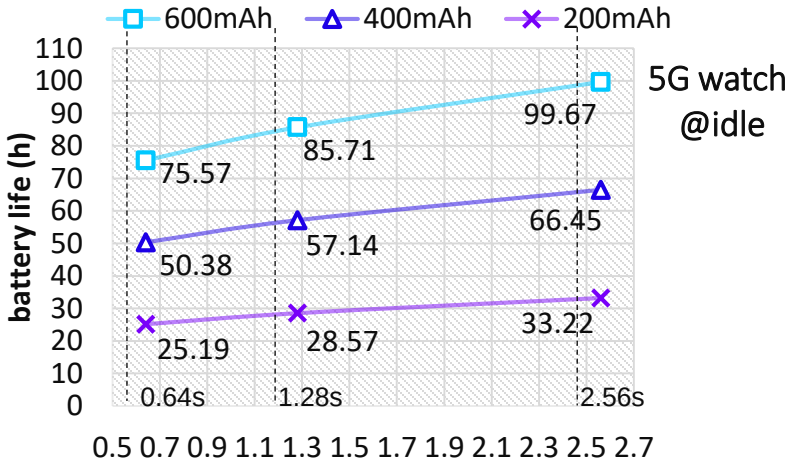
Document for: Discussion & Decision

Agenda Item: 4.3

Ultra-low power wake-up

Challenges

- Use case specific requirements (TR38.875):
  - Industrial wireless sensors: The battery should last at least few years.
  - Wearables: Battery of the device should last multiple days (up to 1-2 weeks).
- Limitation of power saving in Rel 17
  - Battery life of up to 1-2 weeks cannot be met even only in idle mode
  - eDRX is not expected to be configured for wearables due to large latency



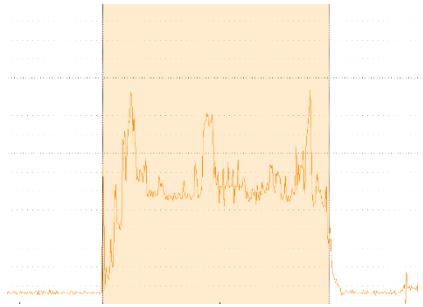
Ideal upper bound: estimated by considering idle mode operation only

Battery life with DRX cycle=1.28s

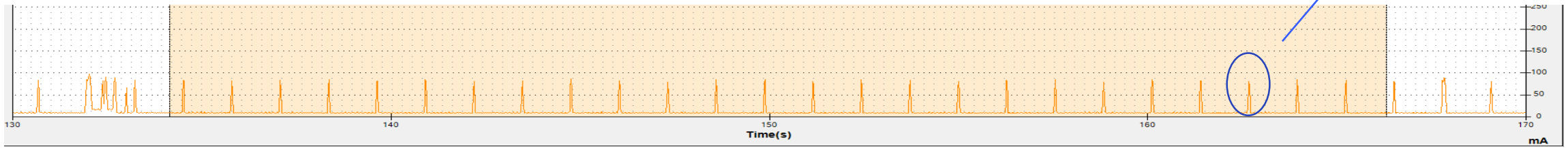
	Average current @idle	Average power @idle	Battery 200mAh	Battery 400mAh	Battery 600mAh
4G watch(1)	4mA	16mw	2.08 days	4.16 days	6.25 days
5G phone(2)	11mA	44mw	0.76 days	1.5 days	2.2 days
5G watch*	7mA(3)	28mw	1.19 days	2.38 days	3.57 days

*Not launched yet, estimated value

Big gap to 1-2 weeks !



Wakeup around PO



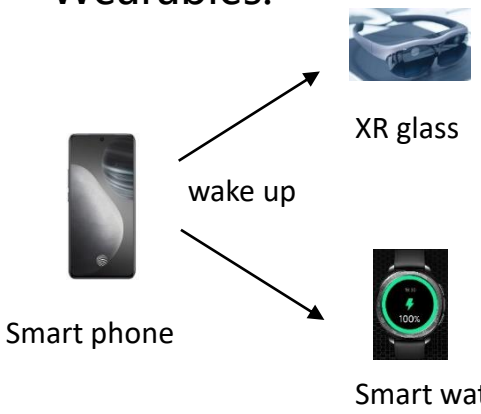
(1) vivo internal testing, TD-LTE
(2) vivo internal testing, 5G NR
(3) Assuming 1RX, scaling based on TR 38.840

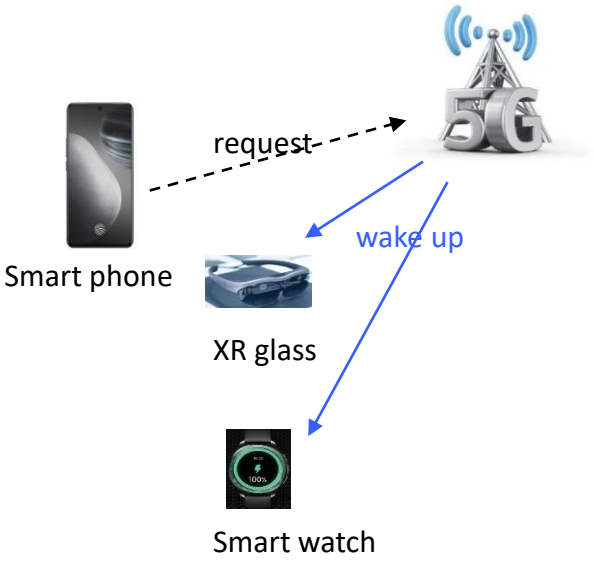
NR UE power consumption, RF + baseband @ RRC IDLE :
Band N41(CMCC), 20MHz, DRX cycle 1.28s

Ultra-low power wake-up

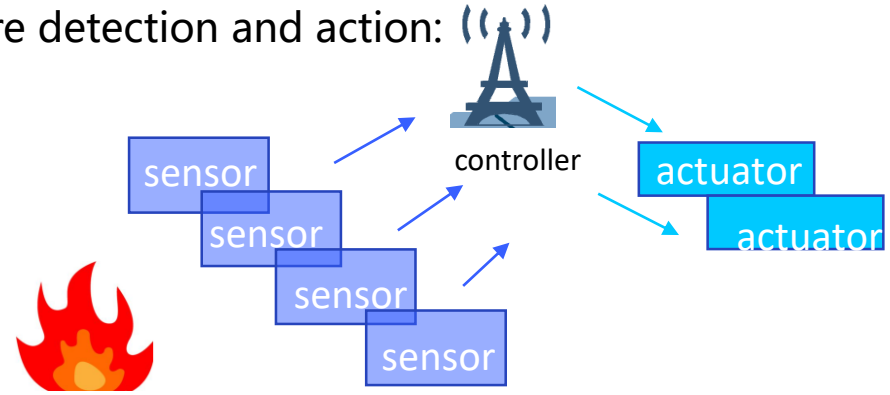
Use cases

- Wearables:



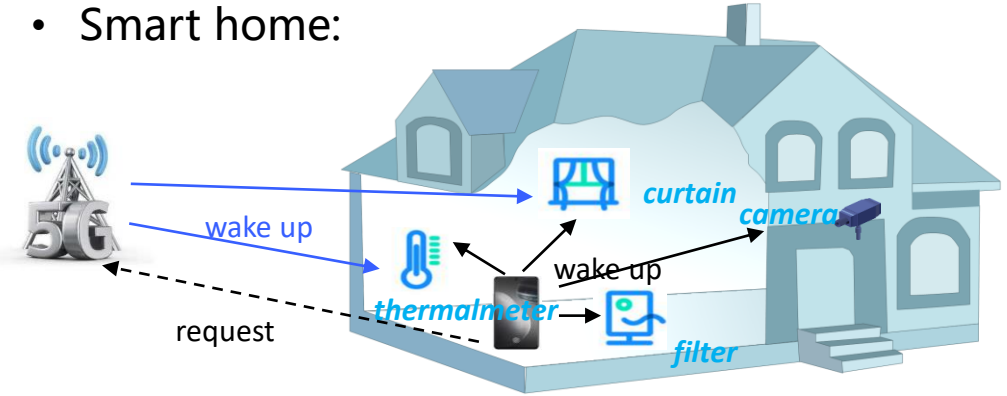


- Fire detection and action:

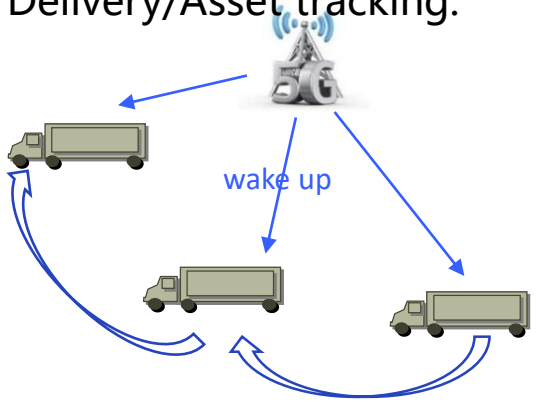


Fire shutters shall be closed and fire sprinklers shall be turned on within 1 to 2 seconds

- Smart home:



- Delivery/Asset tracking:

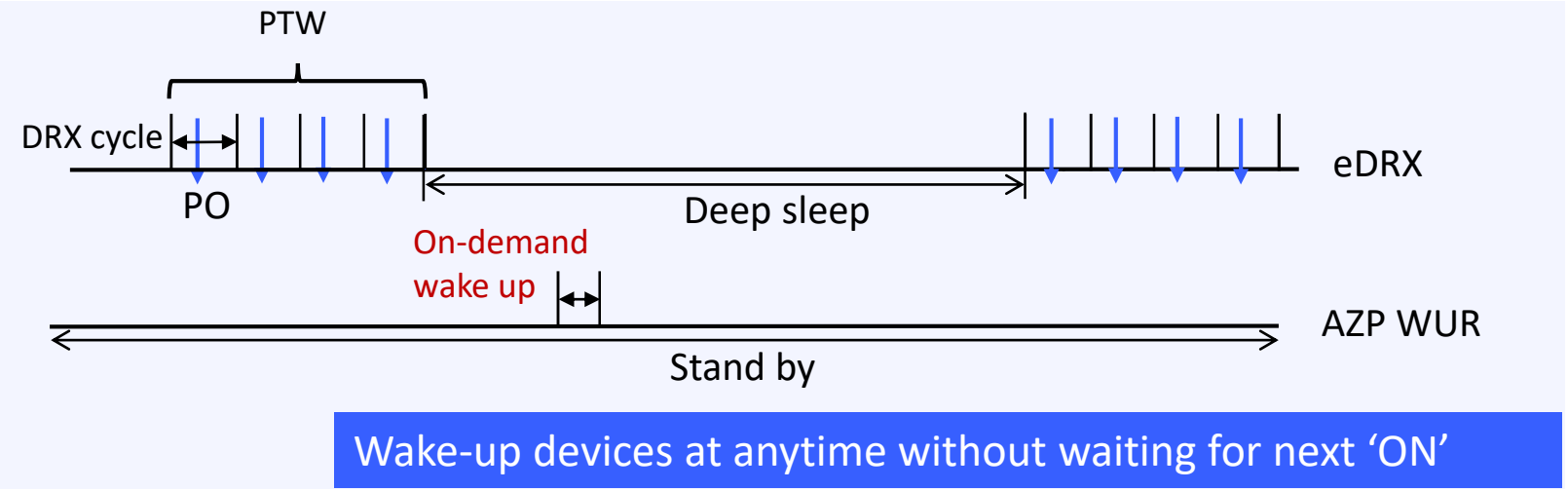


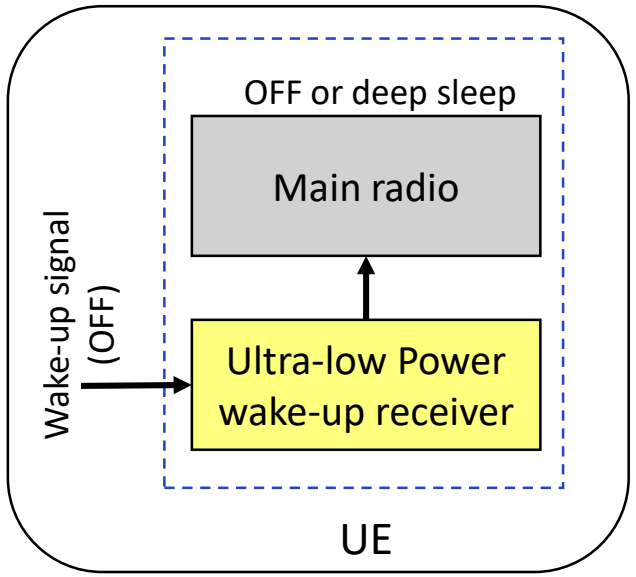
(1) Wearables, battery of the device should last multiple days (up to 1-2 weeks), 3GPP TR38.875 Study on support of reduced capability NR devices
(2) Delivery/asset tracking, 3GPP TR 22.104 Service requirements for cyber-physical control applications in vertical domains
(3) Smart home, 3GPP TR 22.859 Study on Personal Internet of Things (PIoT) networks
(4) Fire detection and action, 3GPP TR 22.804 Study on Communication for Automation in Vertical Domains

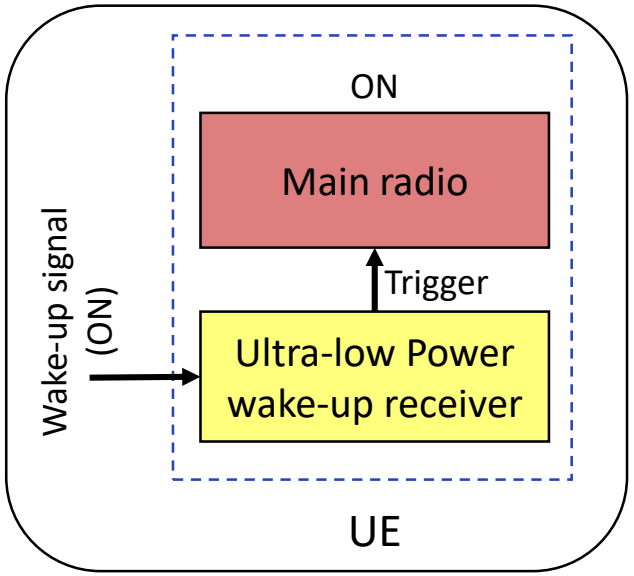
Ultra-low power wake-up

Rel-18 ultra-low power receiver

- The battery life depends on the paging cycle. The system design is a tradeoff between power consumption and latency
  - However, a separate wake-up receiver can wake up devices at any time without long waiting time and still low power consumption







- Separate wake-up receiver can largely reduce the power consumption
  - For main radio, upon reception of the wake-up signal,
    - The ultra-low power receiver wake up the main radio,
    - Otherwise, the main radio is OFF or keep in a deep sleep mode
  - For ultra-low power wake-up receiver,
    - It can be operated in an always 'on' manner with very low power consumption.

Ultra-low power wake-up receiver

Tradeoff between power consumption and RF sensitivity/coverage

- Smartphone and wearables are expected to further reduce the power, for standby purpose

Poor — Power consumption — Good

Good — Coverage — Poor

NR Idle	• Traditionally UE power consumption, RF + baseband @ RRC IDLE • Power consumption **30~50mW**, and RF sensitivity **-100dBm**(1)
Very low Power (VLP)	• A RF front-end receiver with main radio deep sleep or power off • Power consumption **about 1 - 10 mW**, and almost no or minor RF sensitivity degradation

Almost Zero Power (AZP)	• Almost zero power receiver: passive circuit with envelope detector
	  • Power consumption **7.4nW**, and RF sensitivity **-71dBm** @433MHz(2)
	  • Power consumption **99μW**, and RF sensitivity **-97dBm** @2.4GHz (3)
	  • Power consumption **45μW**, and RF sensitivity **-87dBm** @900MHz(4)

Zero Power	• Zero power: energy harvesting • Power consumption **0**, and RF sensitivity**@-20Bm** or higher(5)

- ***Need tradeoff between power consumption and received signal sensitivity***
- ***Almost zero power receiver achieve 100x~1000x power reduction with some sensitivity degradation is feasible.***
- ***Very low power receiver by RF front-end can achieve about 5x power reduction with almost no or minor RF sensitivity degradation.***

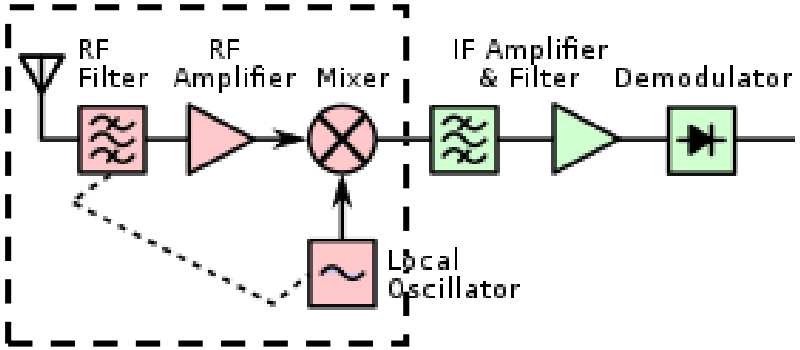
Reference AZP Receiver minimum input

- -77dBm ~ -82 dBm (802.11ba)
- -97dBm [Salazar ISSCC'15]
- -72dBm [Pletcher ISSCC'08]

(1) vivo internal testing, 5G NR
(2) A -76dBm 7.4nW Wakeup Radio with Automatic Offset Compensation, Jesse Moody et al.
(3) A −97dBm-sensitivity interferer-resilient 2.4GHz wake-up receiver using dual-IF multi-N-Path architecture in 65nm CMOS, Camilo Salazar et al
(4) Abe, VLSI'14
(5) NXPRFID, UCODE G2iM https://www.nxp.com/products/rfid-nfc/ucode-rain-rfid-uhf/ucode-g2im-and-g2im-plus:SL3S1003_1013

Ultra-low power wake-up receiver

Very low power (VLP) receiver



- RF front-end receiver consists only some operations such as,
  - band-pass filter (BPF)
  - RF amplifier, i.e., low-noise amplifier (LNA)
  - A local oscillator (LO) which generates a radio frequency signal at an offset from the incoming signal, which is mixed with the incoming signal within a Mixer.
- Compared to a normal data reception, a very low power wake-up receiver
  - may not require digital receivers, such as ADC and IF filtering and demodulation, or digitize the RF signal directly, without down-conversion to an IF
- 'Event-driven style': Tx send wake-up to Rx on demand without Rx stay at 'asleep-yet-alert' state, e.g., no periodically inquiry wake-up or not but keeps monitoring in a ultra-lower consumption level.
- Expected to save power consumption about 3 ~ 5 times.

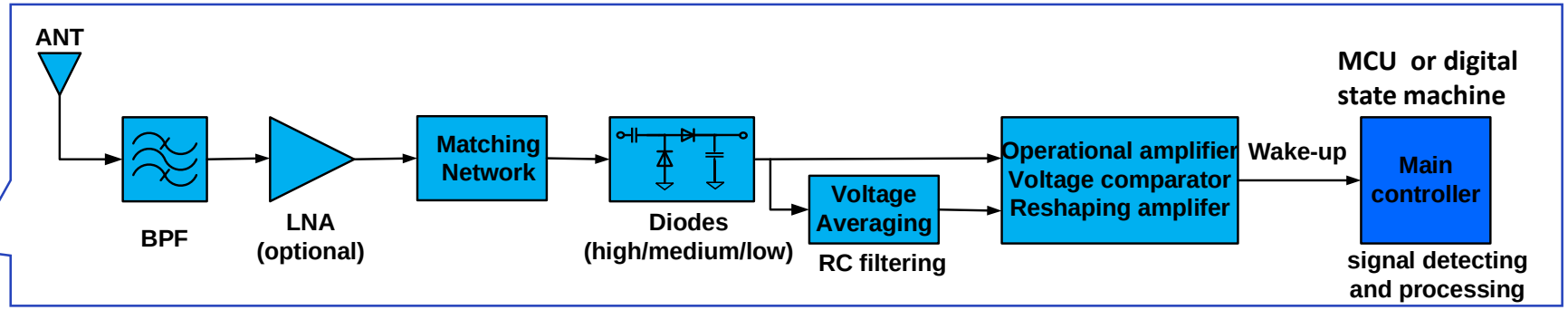
Almost-Zero-Power (AZP) wake-up receiver

Design of passive circuit

- Passive circuit receiver

Network control wake-up

Example receiver architecture



- Key factors to achieve low power consumptions
  - **Remove LNA or less gain: 100~1000uW, voltage gain ~ 10 dB, 2.4GHz**
  - **Remove ADC: by OOK waveform, no ADC is needed, a simple energy accumulation and comparator is enough**
  - **Separate RF channel to the main radio** (but can shared antenna)
  - **Very simple processing by digital state machine or simple MCU**
- 'Event-driven style': Tx send wake-up to Rx on demand without Rx stay at 'asleep-yet-alert' state
  - **Passive circuit**
    - Passive envelope detector (ED of the CMOS RF front-end)
- Expected to save power consumption about 100 ~ 1000 times.

Almost-Zero-Power (AZP) wake-up receiver

Proof-of-concept

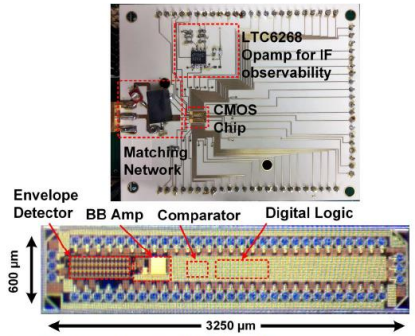


Figure 28.6.7: Die micrograph and PCB photo of the wakeup receiver.

-71dBm, 433MHz, 7.4nW

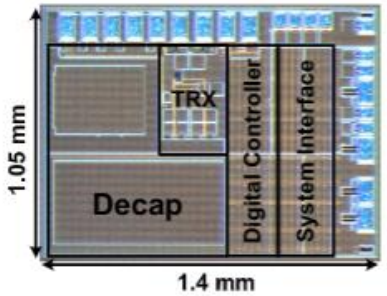
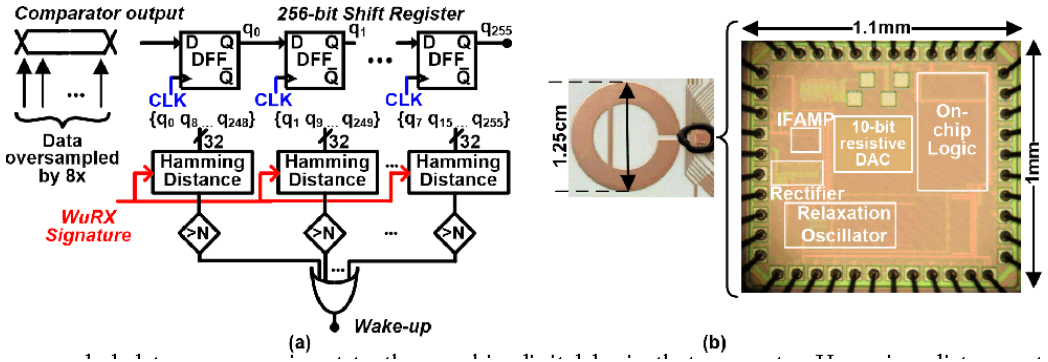


Fig. 16. Radio die photograph in 55-nm DDC CMOS.

-97dBm, 2.4GHz, 99uW



-61.5dBm, 2.4GHz, 365nW

CMOS RF front-end with OOK energy detection which is designed for low power receiver with enough receiving sensitivity is being popularly studied

	Moody ISSCC'18		Jiang ISSCC'17 [1]	Roberts ISSCC'16 [2]	Sadagopan RFIC'17 [3]	Salazar ISSCC'15	Abe VLSI'14	Pletcher ISSCC'08
Technology	130 nm		180 nm	65 nm	65 nm	65 nm	65 nm	90 nm
Carrier Frequency	151.8MHz	433MHz	113.5MHz	2.4GHz	2.4GHz	2.4GHz	925.4MHz	2 GHz
Power Consumption	7.4 nw	7.4 nw	4.5 nW	236 nW	365 nW	99 µW	45.5 µW	52 µW
Data Rate	200 bps	200 bps	300 bps	8.192 kbps	2.5 kbps	10 kbps	50 kbps	100 kbps
Dissipated Energy per bit	37 pJ	37 pJ	15 pJ	28.8 pJ	146 pJ	9900 pJ	910 pJ	520 pJ
Non-constant Envelope Interferer Rejection	Integrated Auto Offset Control Loop		N/A	N/A	N/A	N/A	2-Step Wakeup	N/A
Out-of-band Interferer Rejection Method	High-Q FE Transofrmer		High-Q FE Transformer	Matching Network	High-Q FE Co-Design	N-path filter	2-Step Wakeup	MEMS Filter
Sensitivity	-76 dBm [1]	-71 dBm [1]	-69 dBm [1]	-56.5 dBm [2]	-61.5 dBm [2]	-97 dBm [2]	-87 dBm [2]	-72 dBm [2]
Sensitivity with interference	-76 dBm [3]	N/A	N/A	N/A	-58.5 dBm [4]	-94 dBm [5]	-84 dBm [6]	N/A
Die Area	1.95 mm²		6 mm²	2.25 mm² *	1.1 mm² *	0.0576 mm² *	1.27 mm² *	0.1 mm² *

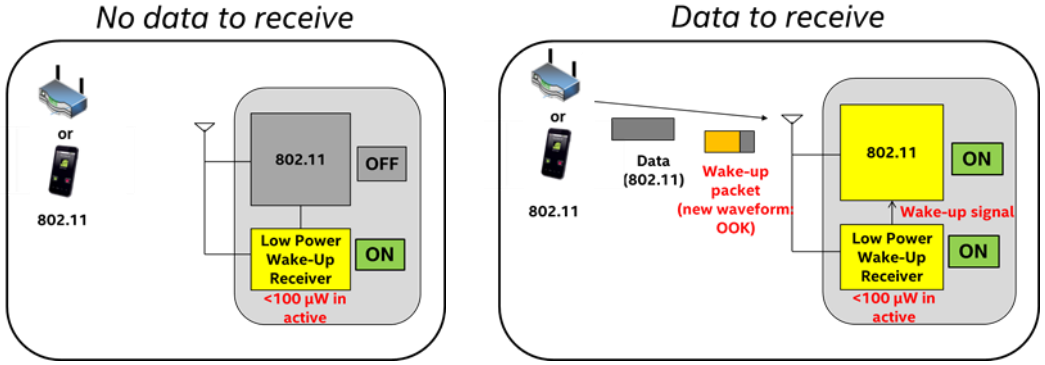
Power consumption:
nw, uw level

Sensitivity:
low to -97 dBm

Almost-Zero-Power (AZP) wake-up receiver

Industrial achievement: IEEE802.11ba

- Comm. Subsystem = Main radio (802.11) + LP-WUR
  - **Main radio (802.11): for user data transmission and reception**
    - Main radio is off unless there is something to transmit
    - LP-WUR wakes up the main radio when there is a packet to receive
    - User data is transmitted and received by the main radio
  - **LP-WUR: <u>not</u> for user data; serves as a simple "wake-up" receiver for the main radio**
    - LP-WUR is a simple <u>receiver</u> (doesn't have a transmitter)
    - Active while the main radio is off
    - Target power consumption < 100 μW in the active state
      - Simple modulation scheme such as On-Off-Keying (OOK)
      - Narrow bandwidth (e.g. < 5 MHz)
    - Target transmission range: LP-WUR = Today's 802.11



30.3.13.1 Receiver minimum input sensitivity

The packet error ratio (PER) shall be less than 10% for a PSDU length of 6 octets with the rate-dependent input levels listed in Table 30-11 (Receiver minimum input level sensitivity).

Table 30-11—Receiver minimum input level sensitivity

Modulation	Minimum sensitivity (dBm)
WUR LDR	-82
WUR HDR	-77

Minimum sensitivity (dBm)
-82
-77

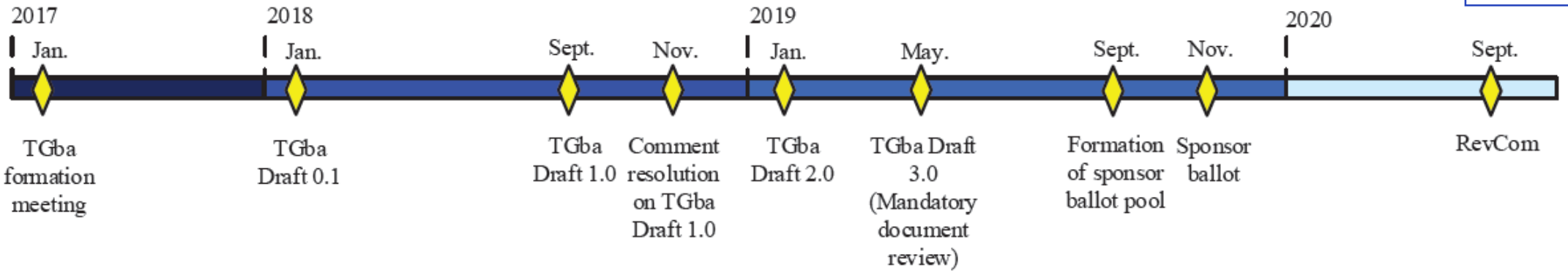
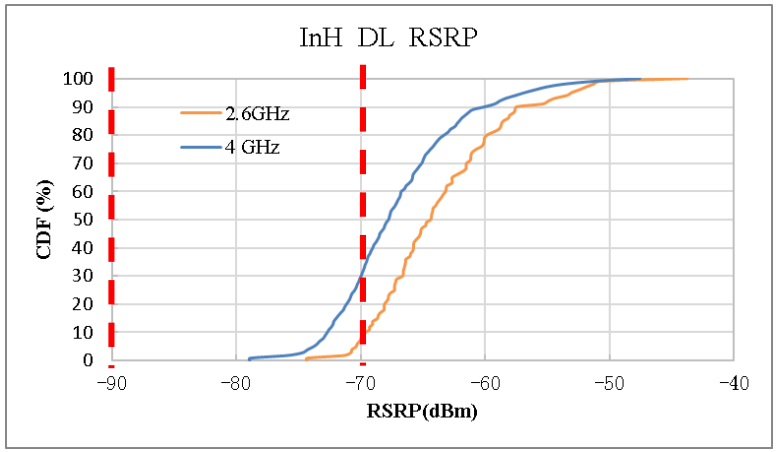


Figure. Timelines of IEEE 802.11ba standardization progress

Almost-Zero-Power (AZP) wake-up receiver

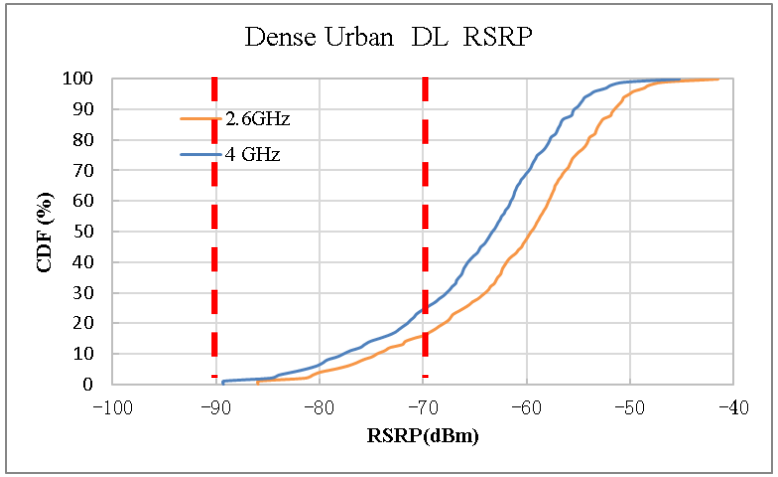
Feasibility in practical deployments

- Design should consider the impact to UE performance
  - The feasibility (e.g., RF sensitivity) is scenario dependent (deployment, UE speed, etc)
  - Network controlled UE behavior



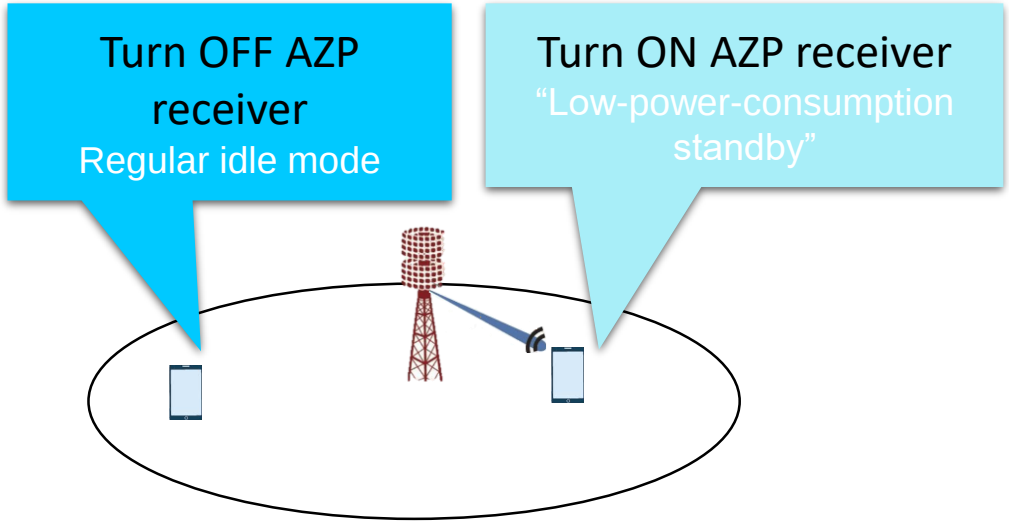
Downlink,

- ☐ **70%-90%**feasible for Near-zero power receiver @ -70dBm
- ☐ **100%** feasible for -90dBm

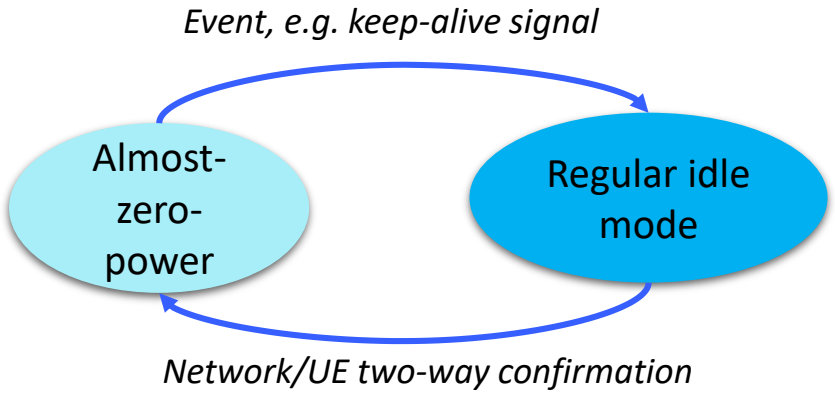


Downlink,

- ☐ **75%-85%**feasible for Near-zero power receiver @ -70dBm
- ☐ **100%** feasible for -90dBm



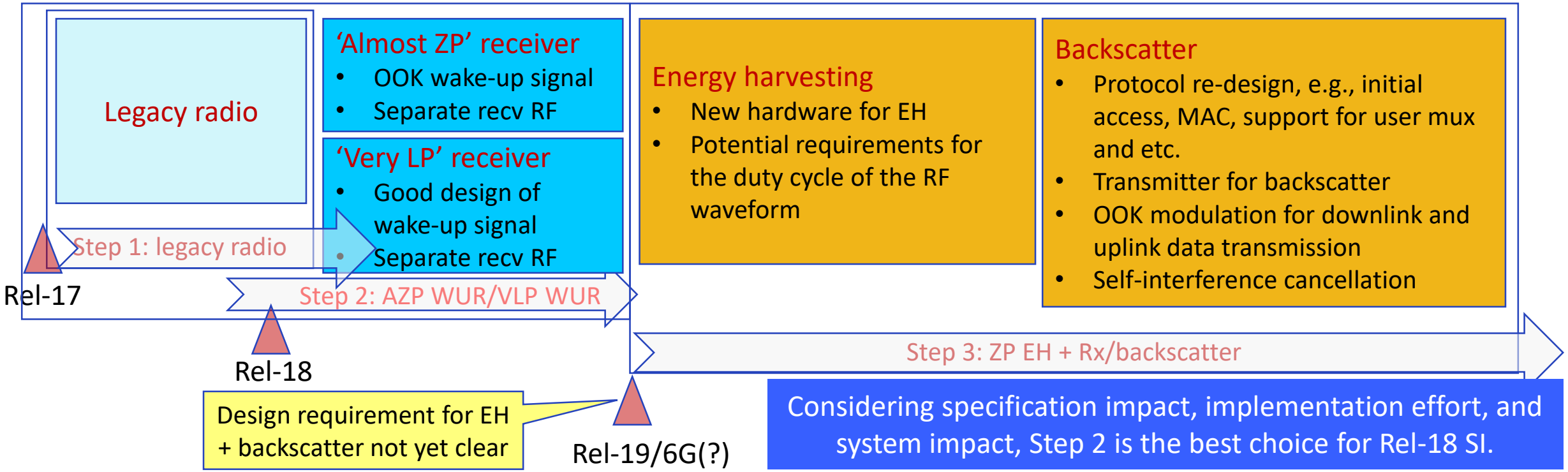
Necessary methods to ensure network and UE reachability.



Almost-Zero-Power (AZP) wake-up receiver

Step-by-step evolution for ultra-low power devices design

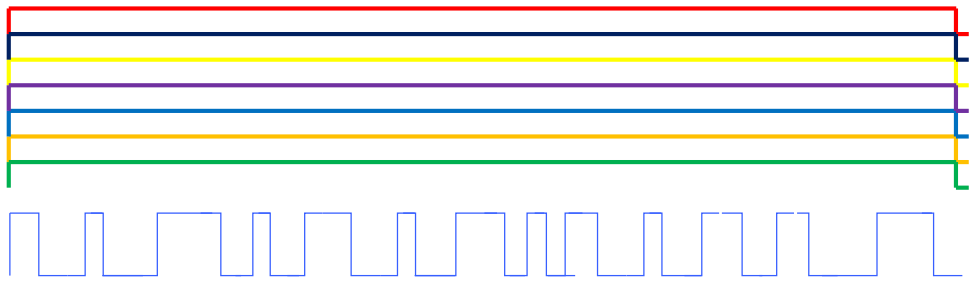
Step	solution	Energy harvesting	Range	Sensitivity	Power consumption	System impact
step1	Legacy radio	N	> 500m	>-100dBm	1 X	
step2	VLP WUR	N	> 500m	>-100dBm	1/3 ~ 1/5 X	less impact to legacy system, target for almost zero power 'paging indication'
	AZP WUR	N	~ 100m	~ -80 dBm	0.001 ~ 0.01 X	
step3	ZP EH + backscatter	Y	~ 10m	~ -20~ -30 dBm	0	Heavy impact to legacy system, target for new 'control' + 'data' Tx/Rx,



Almost-Zero-Power (AZP) wake-up receiver

Designs of near-zero power wake-up signals

- **Performance metrics**
  - With 10^X probability of missed detection and false wakeup rate < Y/hr
  - Wakeup sensitivity of
    - [Z]dBm, i.e., -70dBm - compute the energy required for the wakeup signal detection and power consumption in the detection
    - identify the coverage area based on a given Tx power and receiver sensitivity
  - Power consumption Q, i.e., 100uw
  - More than 10 years standby for sensor, more than 2 weeks for wearables
- **Design of near-zero power wake-up signals**
  - ON/OFF keying
    - single tone signal with modulated signals
    - Multi-tone transmission in time or frequency



- **Design should consider the impact to UE performance and system impact**
  - Network reachability to UE should be guaranteed, e.g.,
    - stationary or low mobility
    - good coverage

Essential improvements for ReCap/eMBB UEs standby operations

Objective of Ultra-low power wake-up signal study in Rel-18

SID

- For UE stand-by, study the ultra-low-power wake up to trigger main radio considering the following aspects:
  - Study and evaluate the trade-off between receiver sensitivity and power consumption considering feasible receiver architectures, e.g., RF/Analog Front-end and/or dedicate wake-up receiver, with ultra-low power consumption [RAN1, RAN4]
  - Study the wake-up signal design enabling the UE wake-up with ultra-low power consumption and efficient system operation. [RAN1 ,RAN4]
    - Basic structure of wake-up signal
    - Narrow bandwidth
    - Multiplexing of wake-up signals
    - In-band and/or out-band operation by considering the following
      - coexistence with the legacy signal/channels for in-band operation
      - inter-cell interference
    - operation on licensed/unlicensed band
    - method to ensure network reachability
  - Study the possible procedures to support the ultra-low power UE wake up [RAN2,RAN1]
    - The ultra-low UE wake up feature is configured by the network
    - UE procedure for ultra-low power wake up signal monitoring
    - UE procedure for main radio activity triggered by ultra-low power wake up signal
    - Potential UE state transition
- Note: The main radio may include but not limited to NR, LTE, sidelink, LTE-M, NB-IOT, etc.

THANK YOU.
谢谢。