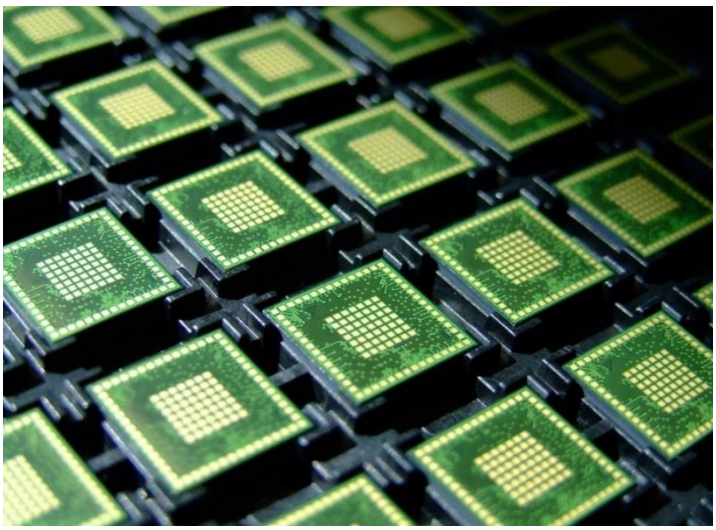
Lemonbeat SiP Chip

System in Package Chip and Software Stack

Version 6.0

Data Sheet

17.05.2018



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1. Lemonbeat SiP Chip

Hardware specification

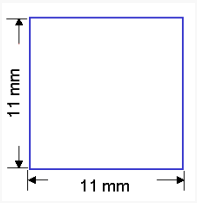
The Lemonbeat SiP (System in Package) module is a complete hardware MCU-RF solution that enables the handling of the Lemonbeat Software Stack and specific application code.
The Lemonbeat SiP Chip makes it easy to implement advanced functionality with an optimized hardware and minimal programming effort because all critical design issues have been integrated into the module.

Characteristics/Highlights

- ETSI certified
- With integrated Lemonbeat Software Stack and 17 integrated services
- Robust high-range Sub-GHz Lemonbeat Radio technology
- Power saving mechanisms
- Security through MAC layer encryption and RSA key exchange

General specification

Manufacturer	Silicon Labs	
Package	LGA105	
Type	Transceiver + MCU	
MCU Core	ARM Cortex-M3 @ 80MHz	SiM3U167-B-GDI
Memory	Flash	256 kb
	RAM	32 kb (4kb retained in power down)
Transceiver	Silicon Labs SI 4460	
Transmit data rate	100 kbit/s	
Operating Temperature	-40 °C to 85 °C	
Size	11 x 11 x 1 mm	



Electrical specification

Operating voltage		+1.8 V to +3.6 V
Wake-on-Radio Event		
Current consumption	WoR_{Peak}	≈ 39.00 mA ± 2mA
	WoR_{Sleep}	≈ 10.5 µA ± 2.0 µA
	$WoR_{Period\_Average}$	≈ 148.0 µA ± 2.0 µA
Period duration	WoR_{Period_WoR}	≈ 330 ms ± 2.0 ms
	WoR_{Peak_WoR}	≈ 1.5 ms ± 0.2 ms

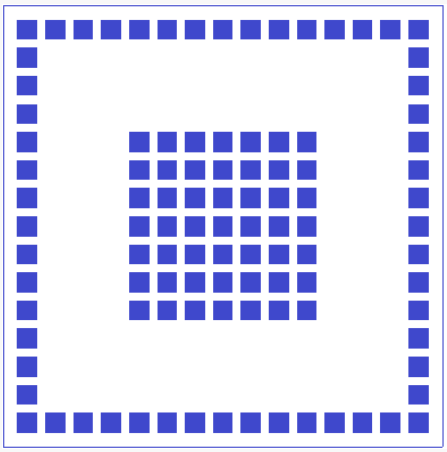
RF antenna

	Frequency range (send/receive)	863.000 to 870.000 MHz
	RF output - impedance (pin 38)	50 Ω

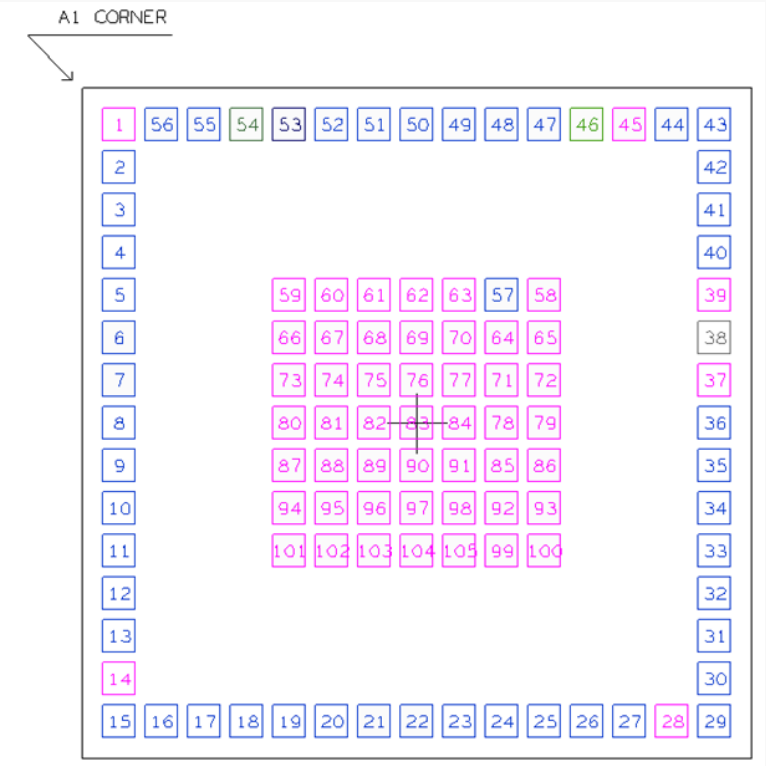
Transceiver		
	Silabs 4460	
Transmit power (Default)		14 dBm (Exception: 27 dBm @ channel 29)
Output power range	min.	-20 dBm
	max.	14 dBm
Power modes	Shutdown	30 nA
	RX on	10.7 mA - 13.7 mA
	TX on	30 mA @ 14 dBm
Modulation		2-GFSK, modulation index 0,7
Sensitivity		-106 dBm (@ BER<0,1%, BW-time-product BT=0.5, delta_f = +-50kHz)
Send/Receive range		863.000-870.000 MHz (30 useable channels)
MCU peripherals		
GPIO	39 pins	
	Up to 4 programmable high drive capable GPIOs (5–300 mA, 1.8–6 V)	
Communication Interfaces	2 x USARTs 1 x UART 1 x SPI 1 x I2C (up to 1 Mbit/sec)	
ADC	2 x 16 channels	12 bit, 250kSamples/s plus internal temp sensor
DAC	2	12 current mode DAC
Analog Comparator	2 (up to 16 inputs)	
DMA	16 channels	
Debug interfaces	JTAG SWD ETM	
MCU hardware blocks		
HW units	Cryptography and CRC	AES 128/192/256 CRC 16/32
Timer	2 x 32 Bit timer 2 x 16 Bit timer (2 channel PWM) 1 x 16 Bit timer (6 channel PWM)	
RTC	1	

2. Chip design

Bottom view



Pinout - top view



Plan LGA pin count:	105
Plan LGA Pitch:	0.7 mm
Plan LGA opening:	0.52 x 0.52 mm
Solder mask opening:	0.45 x 0.45 mm

Center pins is GND, **except** pin 57.

3. TÜV Süd - Test report, No. 5010175435-713018420 (Edition1)

TÜV SÜD Product Service GmbH
Äußere Frühlingstraße 45
94315 Straubing
Germany

Phone: +49 9421 5522-0
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Product Service

Summary

Prüfergebnisse / *Test Results*	Auftragsnummer / *Order No.* **Order of 2013-01-13**

Die Prüfungen wurden nach folgenden Vorschriften durchgeführt:
Tests were performed according to:
EN 300 220-1 V2.4.1
EN 300 220-2 V2.4.1

Durchgeführte Prüfung ***Test performed***	**Prüfergebnis** ***Test result***			
	Erfüllt *Passed*	Nicht erfüllt *Not Passed*	Nicht zutreffend *Not applicable*	Nicht durchgeführt *Not performed*
Frequenzfehler / *Frequency error*	☒	☐	☐	☐
Mittlere Leistung (leitungsgebunden) / *Average power (conducted)*	☒	☐	☐	☐
Effektive Strahlungsleistung / *Effective radiated power*	☒	☐	☐	☐
Spread-Spektrum-Modulation / *Spread spectrum modulation*	☐	☐	☒	☐
Transient Power / *Transient power*	☒	☐	☐	☐
Nachbarkanalleistung / *Adjacent channel power*	☐	☐	☒	☐
Modulationsbandbreite / *Modulation bandwidth*	☒	☐	☐	☐
Nebenaussendungen / *Unwanted emissions in the spurious domain*	☒	☐	☐	☐
Frequenzstabilität bei kleiner Spannung / *Frequency stability under low voltage conditions*	☒	☐	☐	☐
Duty Cycle/ *Duty cycle*	☒	☐	☐	☐
Sendeabschaltung / *Time-out-timer*	☐	☐	☒	☐
Empfängerempfindlichkeit / Receiver sensitivity	☐	☐	☒	☐
Empfänger LBT Schwellwert / *Receiver LBT threshold*	☒	☐	☐	☐
Nachbarkanalselektivität / Adjacent channel selectivity	☐	☐	☒	☐
Blocking / Blocking	☒	☐	☐	☐
Nebenansprechen / Spurious response rejection	☐	☐	☒	☐
Empfänger-Nebenaussendungen / Receiver spurious radiation	☒	☐	☐	☐
LBT Zeitparameter / LBT timing parameters	☒	☐	☐	☐

Bemerkungen / *Remarks:*

Die Prüfergebnisse beziehen sich ausschließlich auf das zur Prüfung vorgestellte Prüfmuster. Ohne schriftliche Genehmigung des Prüflabors darf der Prüfbericht auszugsweise nicht vervielfältigt werden. *The test results relate only to the individual item which has been tested. Without the written approval of the test laboratory this report may not be reproduced in extracts.*

Datum / *Date*	Geprüft von / *Tested by*	Freigabe durch / *Checked by*
2013-04-22	Martin Steindl Responsible for testing	Johann Roidt Laboratory manager

Prüfergebnis / *Test Result*
☒ **Erfüllt / *Passed***
☐ **Nicht erfüllt / *Not passed***

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TÜV Süd - Test report, No. 5010175435-713018420 (Edition1)

Device typ:	RF-Module for the 863 MHz
Type:	RF-Module
Serial number:	1

Summary of the main test results

TX

Frequency error	<14.27 ppm at -20°C...55°C
Max. transmit power	14 dBm
Transmit power deviation	<1 dB at -20°c...55°C
Unwanted emissions in the spurious domain	<-48.1 dBm at 10 dBm transmit power
Frequency stability	<5.21 ppm at 2.8V...5V
Duty cycle	Class 4 (up to 100%) at LBT (Listen before talk) and AFA (adaptive frequency agility)
Transient power	<-30.2 dBm (+/-100 kHz), <-39.45 dBm (+/-220 kHz)
Modulation bandwidth	869.9622 kHz - 863.13 kHz

RX

Receiver sensitivity	<-100.6 dBm
Receiver LBT threshold	-87 dBm
Receiver spurious radiation	<-47 dBm (radiated at 3.7 GHz) <-72.2 dBm (conduced)
Blocking of LBT receiver	56 dB (+/- 2MHz) and >59 dB (+/- 10 MHz)
LBT timing parameters	• compliant with ETSI EN 300 220-1 V2.4.1 (2012-05) • minimum listening time: 5 ms + random(16ms) • maximum TX ON-time: 123 ms (single transmission)

4. Lemonbeat SiP Chip pin configuration

Allocations of the pins

Please note that the following pin allocations are the current allocations on the DDk board.
Do **not change** these allocations (this applies to fixed ones, marked in red, and unfixed ones).

#	Type	Pin name	Description
1	PWR	GND	Ground
2	Standard I/O	PIO 3.0	General Purpose 3.0
3	Standard I/O	PIO 3.1	General Purpose 3.1
4	Standard I/O	PIO 3.2	General Purpose 3.2
5	Standard I/O	PIO 3.3	General Purpose 3.3
6	Standard I/O	PIO 2.0	System Switch
7	Standard I/O	PIO 2.1	System LED
8	Standard I/O	PIO 2.6	General Purpose 2.6
9	Standard I/O	PIO 2.7	General Purpose 2.7
10	Standard I/O	PIO 2.8	General Purpose 2.8
11	Standard I/O	PIO 2.9	General Purpose 2.9
12	Standard I/O	PIO 2.10	General Purpose 2.10
13	Standard I/O	PIO 2.11	General Purpose 2.11
14	PWR	GND	Ground
15	Standard I/O	PIO 2.12	General Purpose 2.12
16	Standard I/O	PIO 0.0	(USART0_TX)
17	Standard I/O	PIO 0.1	(USART0_RX)
18	Standard I/O	PIO 0.2	(USART0_RTS)
19	Standard I/O	PIO 0.3	(USART0_CTS)
20	Standard I/O	PIO 0.4	(SPI0_SCK)
21	Standard I/O	PIO 0.5	(SPI0_MISO)
22	Standard I/O	PIO 0.6	(SPI0_MOSI)
23	Standard I/O	PIO 0.7	(SPI0_NSS)
24	Standard I/O	PIO 0.11	(USART1_TX)
25	Standard I/O	PIO 0.12	(USART1_RX)
26	Standard I/O	PIO 0.13	(USART1_RTS)
27	Standard I/O	PIO 0.14	(USART1_CTS)
28	PWR	GND	Ground
29	Standard I/O	PIO 1.9	(UART1_CTS)
30	Standard I/O	PIO 1.8	(UART1_RTS)
31	Standard I/O	PIO 1.7	(I2C0_CLK)
32	Standard I/O	PIO 1.6	(I2C0_SDA)
33	Standard I/O	PIO 1.5	General Purpose 1.5

Pin #	Type	Pin name	Description
34	JTAG	SWCLK, TCK	JTAG TCK
35	JTAG	SWDIO, TMS	JTAG TMS
36	RESET	/RESETB	Global reset for module
37	PWR	GND	Ground
38	RF	RF	RF port 50Ω
39	PWR	GND	Ground
40	Standard I/O, JTAG	PIO 1.4 TDI	JTAG TDI
41	Standard I/O, JTAG	PIO 1.3 TDO, SWW	JTAG TDO
42	Standard I/O, JTAG	PIO 1.2 TRST	JTAG TRST
43	Standard I/O	PIO 1.1	(UART1_RX)
44	Standard I/O	PIO 1.0	(UART1_TX)
45	PWR	GND	Ground
46	PWR	VCC	Power for module
47	PWR	VREGIN	Input to internal LDO
51	Standard I/O	PIO 4.2 High Drive I/O	High Drive I/O
52	Standard I/O	PIO 4.3 High Drive I/O	High Drive I/O
53	PWR	GND HD	GND for High Drive I/O
54	PWR	VCC HD	VCC for High Drive I/O
55	Standard I/O	PIO 4.4 High Drive I/O	High Drive I/O
56	Standard I/O	PIO 4.5 High Drive I/O	High Drive I/O
57	Standard I/O	TEST (GPIO3)	Do not connect
58-105	PWR	GND	Ground

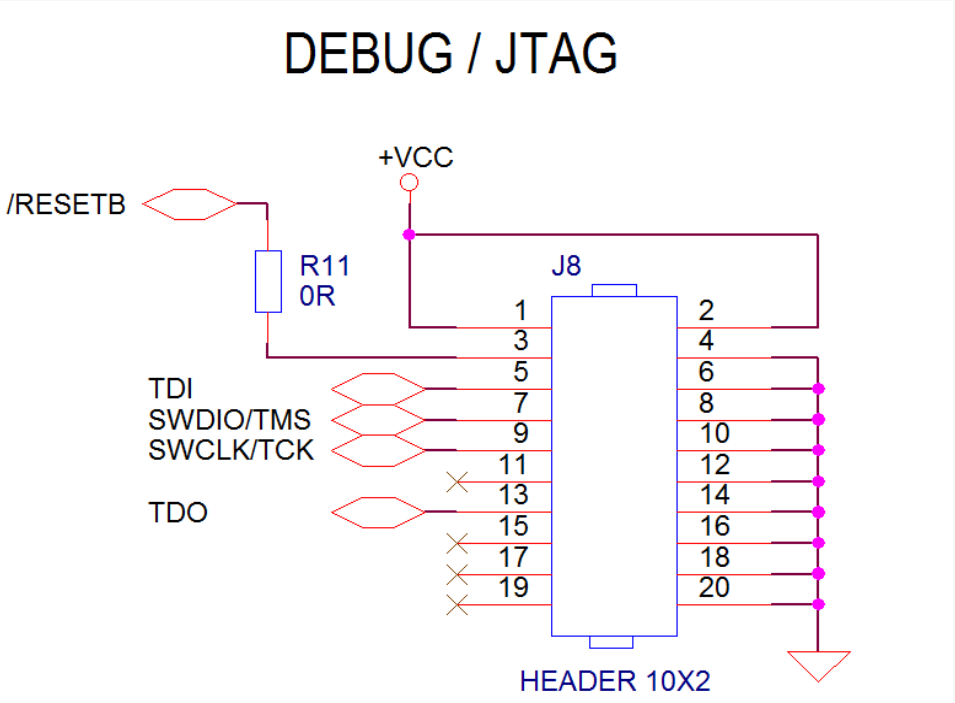
5. Programming and debugging

The module can be programmed via the JTAG or SWD interface. The JTAG programmer/debug interface uses the following signals on the SiP module:

Pin #	Function	Description
41	TDO	JTAG Test Data Out
40	TDI	JTAG Test Data In
34	TCK	JTAG Test Clock
35	TMS	JTAG Test Mode Select
36	/RESETB	Reset

Note
Pin allocations formatted in **red** are fixed allocations that cannot be changed.

The JTAG interface can be implemented like this:



Standard JTAG programmers are using a 2x10 pin header with 2.54mm spacing.
An adapted programming chain and OPENOCD JTAG tool is available to support programming and debugging.

6. Soldering profile

Important note

Pay special attention to the following recommendations to achieve optimal mounting conditions for all chips and thereby to eliminate any chance of chips malfunctioning.
Keep in mind that these are ***recommended values*** that can vary depending on process conditions and assembly machine.

Prior to soldering
Delivery conditions of the chip ex work:
Open and without protection against moisture.

For optimal soldering conditions, we ***strongly recommend*** baking the chips before processing.

a) Baking
   We advise to adhere to J-STD-020E , point 5.4:
   Bake the sample for 24 hours minimum at 125 +5/-0°C.

b) We recommend using a solder paste stencil with a thickness of 100µm and quadratic pads of 0.45 x 0.45 mm (18 x 18 mil) without reduction.

c) Layout guideline
   Apart from one pad (test pin), all pads in the middle are GND. For a proper soldering of these pads, we recommend connecting GND with simple serpentine traces, instead of as a complete surface or with heat-traps.
   This applies to the lower layers to keep the heat shielding in the soldering process as low as possible.
   Please note that it is also possible to solder all outer pads and only some of the pads in the middle; we strongly recommend soldering all pads to ensure the chip functions properly.

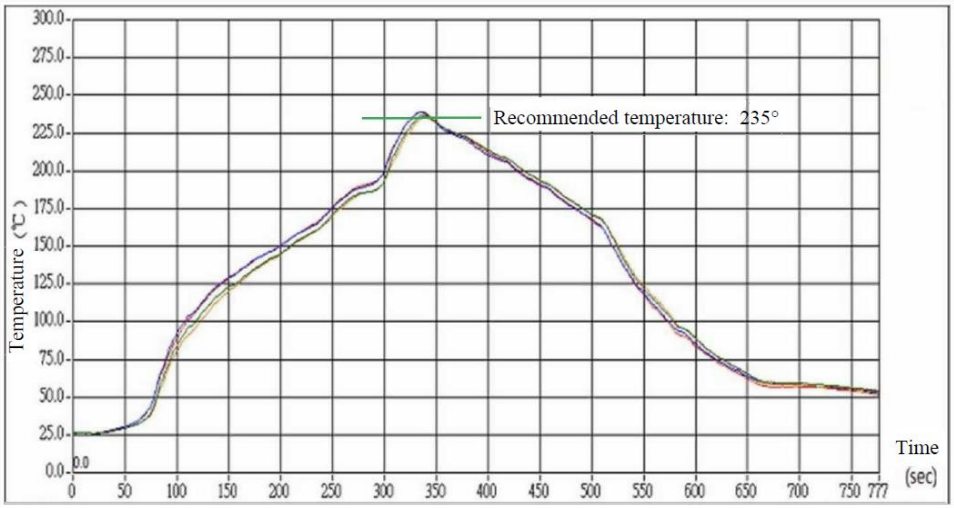
d) Keep in mind that the chip is temperature-sensitive; assure to avoid overheating during the soldering process

Heating phase
Increase the temperature slowly. If the temperature is raised too quickly, the chip can become defective.
Please note that the optimal heating phase can vary from machine to machine.

Soldering

1. If possible, use Vapor Phase Reflow soldering/Vapor Phase soldering. Alternative, you can use a reflow oven.
2. First solder the components that need a higher temperature and then the components that need a lower temperature (i. e., from hot to colder).
3. The following conditions apply:
   - Peak temperature of the chip: ≤ 235°C
   - Liquid phase time: 30 to 60 s
   - Heating gradient: ≤ 4°C/s

   The displayed soldering profile is only an example. We recommend remaining under the shown peak temperature.



Quality control

For each assembly process machine, we recommend that you perform a soldering test, observing the steps and conditions under "Soldering". Afterwards follow these quality steps:

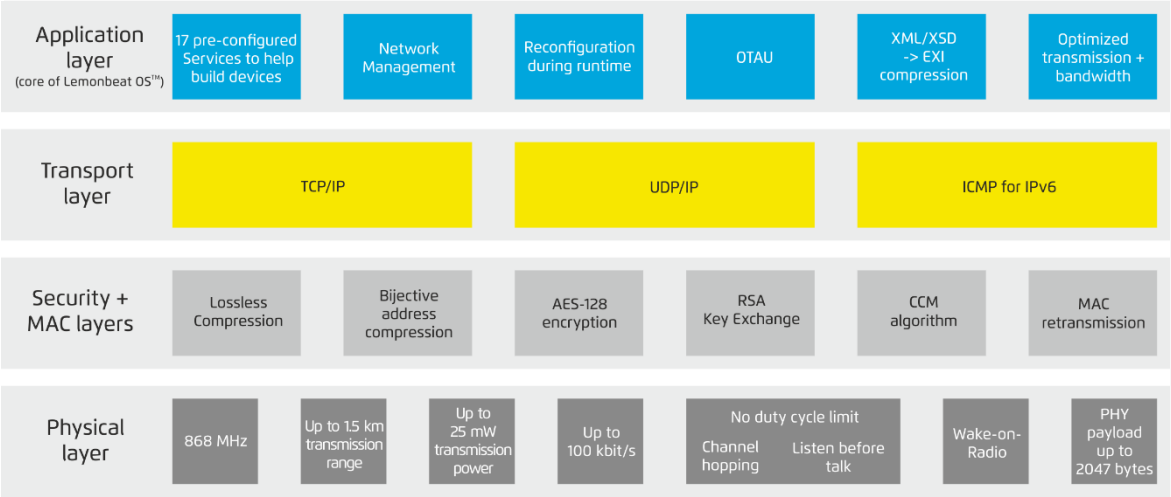
1. Check all soldering joints; where necessary, use X-ray.
   Note
   Soldering joints below the SiP Chips cannot be checked directly.
   Therefore, a possibility to make X-ray examinations is recommended.
2. If all joints are optimal, you can continue the soldering process with the assembly machine under the same conditions.
   OR
   If not, continue with 3.
3. If there are defective or suboptimal joints, change the liquid phase time and/or heating gradient (see step 3. under "Soldering").
3. Perform a soldering test under the new conditions, and continue with step 1., until all joints are optimal.

Further reference

lemonbeat GmbH recommends following the document J-STD-020E as well as IPC-7801, published by Accociation Connecting Eletronics Industries (IPC).

7. Lemonbeat Software Stack

The Lemonbeat Software Stack is a modern IoT protocol that enables direct device to device interaction and contains a pre-configured Application layer (the core of Lemonbeat OS™) to simplify building of intelligent and future-proof smart devices.



Features of the Phy + MAC layer

- Robust digital modulation scheme
- 32 channels at 863-870/868 MHz ISM band
- PHY level data rate 100 kbit/s
- Transmit power: 25 mW (all channels), 500 mW (channel 29)
- Adaptive frequency agility/channel hopping scheme
- Low impact due to frequency fading
- No duty cycle restrictions
- Separation of data channnels and synchronization channels
- Channel access: CSMA/CA, listen before talk
- Supports Wake-on-Radio and Wake-on-Event for battery operation
- Forward error correction (FEC): Hamming or LDPC
- 0-2047 bytes payload per PHY frame
- Multicast addressing support
- State-of-the-art embedded security standards:
  - AES-128 (MAC layer)
  - Cipher Block Chaining-Message Authentification Code (AES-CCM)
  - RSA key exchange
  - Protection against replay attacks by uinsg NONCE (MAC layer)
  - Timestamp checks for secure value report transmission
  - Creation of manufacturer specific network to lock out "foreign" devices
  - Secure device to device interaction through partnering

Features of the Transport layer

- Support of TCP and UDP

  Note

  Currently only UDP is supported for devices that use Wake-on-Radio or Event Listener strategies.

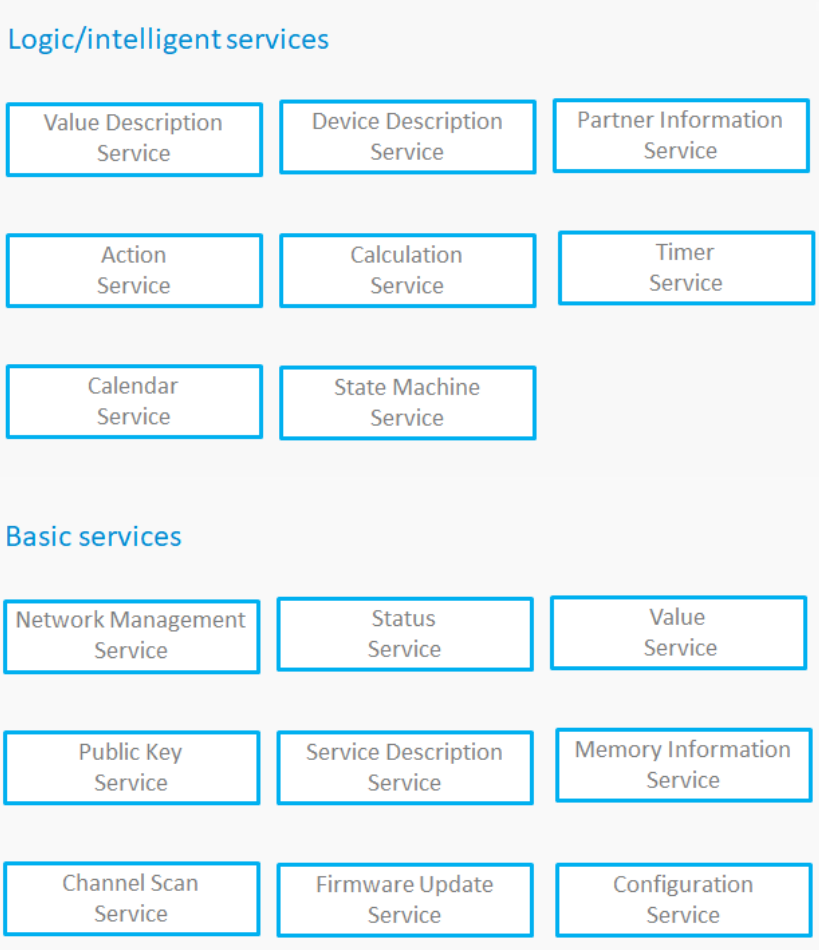
Features of the Application layer

- Lemonbeat smart Device Language (LsDL) as XML API
- Based on well-known W3C standard: XML, XSD, EXI
- Low protocol overhead due to compressed XML (EXI) transmission
- Flexible and self-describing devices and services
- Highly reconfigurable at run-time
- Protocol suited for any scenario and application
- Independent of underlying layers, compatible with other transport media
- Service-oriented interface
- Closes gap between embedded firmware and high-layer software
- Definition of complex logics/user stories
- Network topology
  - Device to device interaction
  - Independent of central controller

8. Lemonbeat OS™ Services

Lemonbeat OS™ offers its core functionalities as services. These services are pre-defined on the Lemonbeat devices. A device that uses Lemonbeat OS™ can describe itself, as well as the value or values that it reports, in an intelligent manner. With some of the Lemonbeat Services the behavior and logic of a device can be changed on the fly, without the need to create a new firmware.

Each service is listening on TCP and UDP using separate ports. Each Lemonbeat Service has a defined destination port (20000-20016). Every time a configuration is performed via XML- or C-API, the transmitted EXI message also contains the respective port number so that the correct Lemonbeat Service is addressed on the device.



8.1 Logic/intelligent services

Used to configure the logical engine of Lemonbeat.
Can be configured via XML API or C API.

Value Description Service

For creating Lemonbeat variables.
Variables are created as virtual value descriptions for which the following can be set:

Access types:	read/write/read-write
Data format:	double/hexadecimal/string
Attributes:	name, min./max. values, step width, unit in SI format (International System of Units

Device Description Service

Transmits device description messages that contain information about the device, e.g. device type, manufacturer, etc., as well as about the radio mode of the device: grid powered/Wake-on-Radio/Event Listener

Due to this service any network controller can automatically gather the required information on how to communicate with the respective device. For Wake-on-Radio devices you can configure a dedicated wake-up channel, allowing a precise wake-up of one device without affecting the others.

Partner Information Service

Communication between network controller and device is always enabled. To allow two devices to communicate with each other, they must be partnered with each other. This means that a device inclusive correct radio mode has to be defined in the partner list of the other device specifying the correct radio mode of the other device. “Partnered” devices can accept message from each other. Partnered devices can also be assigned to a group.

Action Service

Enables various operations like the following on a device:

- Getting/setting a value on a device or partnered device
- Sending a report with a value status to the network controller or partner
- Starting/stopping a timer

Calculation Service

Part of the logical engine of a Lemonbeat device. Can be used to perform several arithmetical operations on double values or to check certain conditions. A calculation consists of two sides, left and right, and an operator. A side can be a constant value, a reference to a value, local or from a partner, or another calculation. It can also check if a timer or calculation has executed or if a state machine is in a specific state. Calculations can refer to other, nested calculations.

Timer Service

For executing actions with a delay. The timer only executes an action if the related condition is met. The timer will trigger a state change in the logic engine.

Calendar Service

Necessary pre-condition: the device needs to be synchronized with NTP.
If this is met, the service enables the following:

- Setting up a calendar task to execute an action once at a specific date/time or repeatedly at a specific interval
- Setting a filter value that specifies the weekdays on which the calendar task is executed

State Machine Service

A state machine consists of states and transactions. A state has an ID so that it can be referenced. A transaction can have a calculation, an action and the state to which the state machine should move in the next step. If the transaction has no calculation, it is interpreted as always true. If the transaction has no next state it should take, the state machine will remain in its current state.
The state machine can be triggered by any local status change of the device, for example: timer event/calendar event/pressing of physical button etc.

8.2 Basic services

Additional services that are not directly related to the device configuration.

Network Management Service

For including a device in the Lemonbeat network by sending it the valid AES network key for the network. For security reasons, the RSA encryption algorithm is used to send the network key from the network controller to the device. Each device, that should be included, gets its own public/private RSA key pair. The public key of the device is used to encrypt the network key. The network controller can receive this public key, for example, from a cloud service or from the device itself if the Public Key Service is enabled.

Status Service

For sending status messages (info/error/important) to the network controller. Application developers are allowed to create custom status messages using the Status Service.

Value Service

For handling value updates and value reports. The service uses values that are defined using the Value Description Service, for example, variables in other languages. Furthermore, custom behavior can be implemented by using state machines and calculations.

Public Key Service

For getting the RSA public key by the network controller. This is one way for getting the public key to include a device. Alternative, getting the public key via web service is possible.

Service Description Service

For sending the network controller a list of all active services on a device upon request. Due to this information the network controller will know which services it can use (for example, Calendar Service, Timer Service or any other Lemonbeat service.) This is an important part of the self-explanatory Lemonbeat technology approach.

Memory Information Service

Most Lemonbeat Services can be extended with custom configurations, for example, with custom calendar entries as well as timers and calculations. Due to memory limitations, the number of configurable items is restricted. The Memory Information Service is used to report the number of (free/used) timers, actions, etc., for a specific device.

Channel Scan Service

Available on the network controller.
The service creates a report about the utilization of the different channels that can be used for Lemonbeat Radio. Using the Channel Scan Service, the network controller decides which channels are most suitable as data channels in the network.

Note:
Channel 3 and 29, that are used as synchronization channels, are preset on all Lemonbeat devices.

Firmware Update Service

Lemonbeat Firmware can be updated via OTAU (Over-the-air-updates). The firmware consists of the following parts: a boot loader, the Lemonbeat Library and the application. Updates can be paused at any time.

Configuration Service

For persisting and enabling the current configuration. When a device receives a configuration change, the configuration status changes to “started” and the device sends a status message. Furthermore, the state machine, timer and calendar are halted, until the configuration is switched backed to idle again. For the received configuration to become effective, it must be saved. Otherwise a timeout will happen after 30 seconds of inactivity and the configuration on the device will be rollbacked to the last committed configuration.

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