Wireless Networking [ET4394]

Narrow-band Internet of Things (NB-IoT)

Melike Sezen Ozdemir

March 2018

Learning Objectives (LOs)

- **LO1:** Learning about the 3GPP specifications and technical properties of Narrowband IoT technology
- **LO2:** Understanding the strengths and weaknesses of NB IoT by comparing to other LPWAN Technologies
- **LO3:** Gaining insight on further uses of this technology

Literature Review

- A Primer on 3GPP Narrow-band Internet of Things
NB-IoT system for M2M communication, Y.-P. Eric Wang et al,
http://ieeexplore.ieee.org/document/7876968/

- NB-Iot whitepaper: Rohde & Schwartz
https://cdn.rohde-schwarz.com/pws/dl_downloads/dl_application/application_notes/1ma266/1MA266_0e_NB_IoT.pdf

- TU Delft, M.Sc thesis, Nair, Varun
Evaluating the suitability of Narrowband Internet-of-Things (NB-IoT) for smart grids
https://repository.tudelft.nl/islandora/object/uuid:29bc9edf-122b-4adf-b2e6-35504a2454fc

- A Smart Parking Project demo on YouTube, NB IoT Smart Parking, Ericsson
https://www.youtube.com/watch?v=U-yPdrDwE9E

Introduction to NB-IoT

- The 3rd Generation Partnership Project (3GPP), is a collaboration that organizes and manages the wireless communications standards. *Such as GSM, 3G UMTS, LTE, 5G*.

- 3GPP releases the standards for NB-IoT, the new narrowband radio technology developed for the Internet-of-Things.

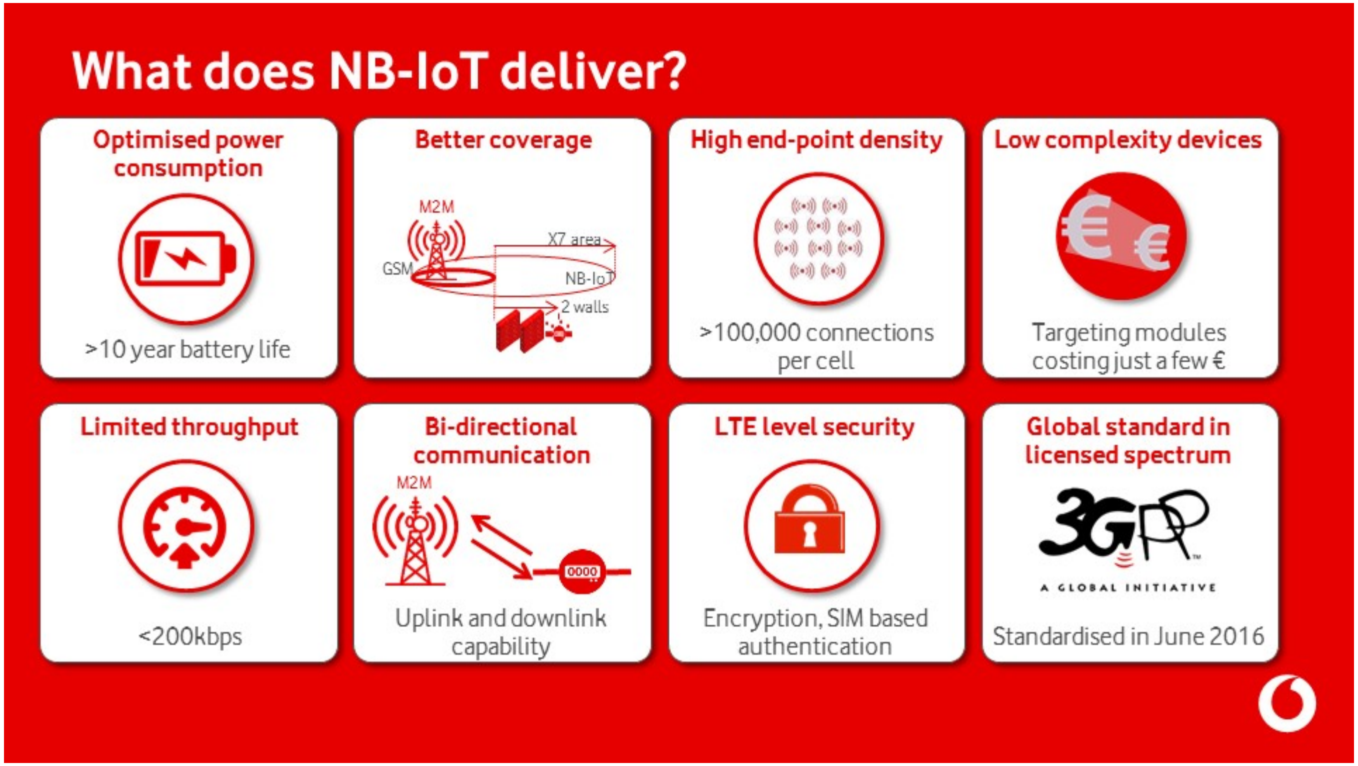
- http://www.3gpp.org/about-3gpp/about-3gpp

- http://www.3gpp.org/news-events/3gpp-news/1785-nb_iot_complete

- http://www.3gpp.org/images/PDF/R13_IOT_rev3.pdf

Market terms of NB-IoT

- Narrowband IoT is advertised by operators with following terms, some of which we will check in this lecture.



https://www.vodafone.nl/midden-groot-bedrijf/oplossingen/internet-of-things/narrowband-iot/

LPWAN architecture

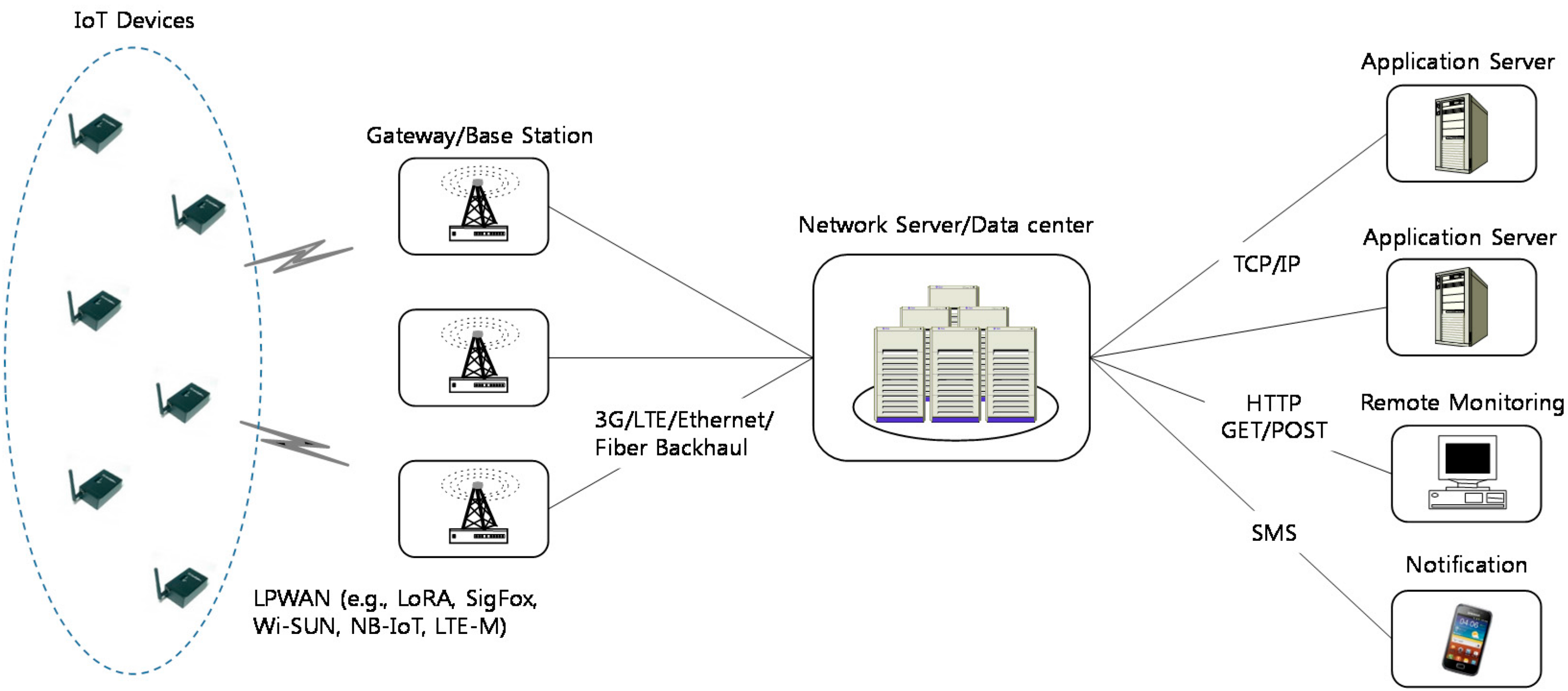


Figure: LPWAN end-to-end network architecture for Internet of Things

http://www.mdpi.com/1424-8220/17/12/2818/htm

NB-IoT Module Energy Consumption

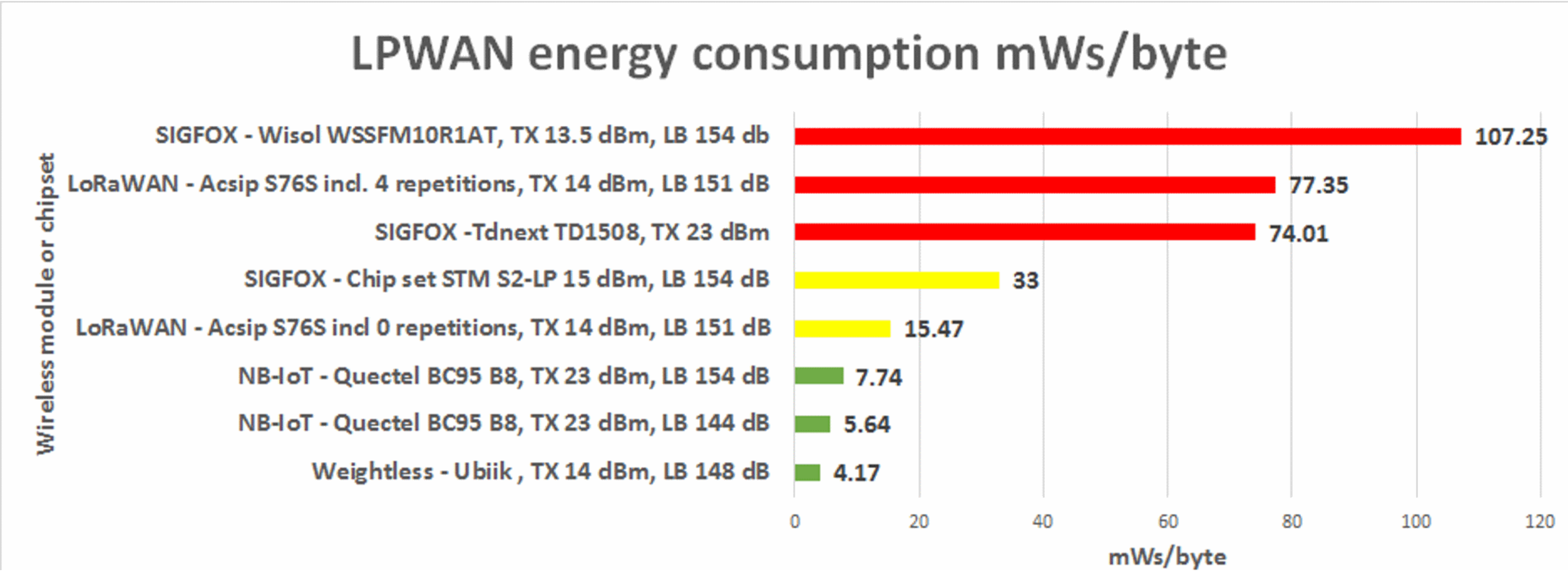
- Calculations of energy consumptions are performed per byte base, on measured packet traffic data.
- For NB-IoT, energy calculation is as follows:
  - 512 bytes were transmitted by the NB-IoT module in 17 separate data packets by UDP/IP.
  - On the first quick look, 30 bytes per burst were detected.
  - On second look another page is showing a variation from 8 to 140 (SMS); 200 to 512 bytes and everything in between.
  - On better link budget than the energy consumption will be already lower than mentioned 5.64 per byte.

The other LPWAN Technologies:

	SIGFOX	Weightless	IEEE 802.11ah
Key Feature	Ultra Narrow-Band modulation	Fully acknowledged transmissions	Very variant Modulation Schemes
Modulation Format	DBPSK – uplink GFSK – downlink.	GMSK and offset-QPSK modulation	BPSK, QPSK, 16-QAM, 64-QAM or 256-QAM
Data Rate	100 or 600 bps	625bps to 100kbps	347 Mbps
Bandwidth	200 kHz Each message is 100 Hz wide	Narrowband 100kHz (8 x 12.5kHz sub-channels)	16 MHz
Provider Website	https://www.sigfox.com/en	https://www.ubiik.com/	https://www.wi-fi.org/discover-wi-fi/wi-fi-halow

Power consumption of LPWAN Modules

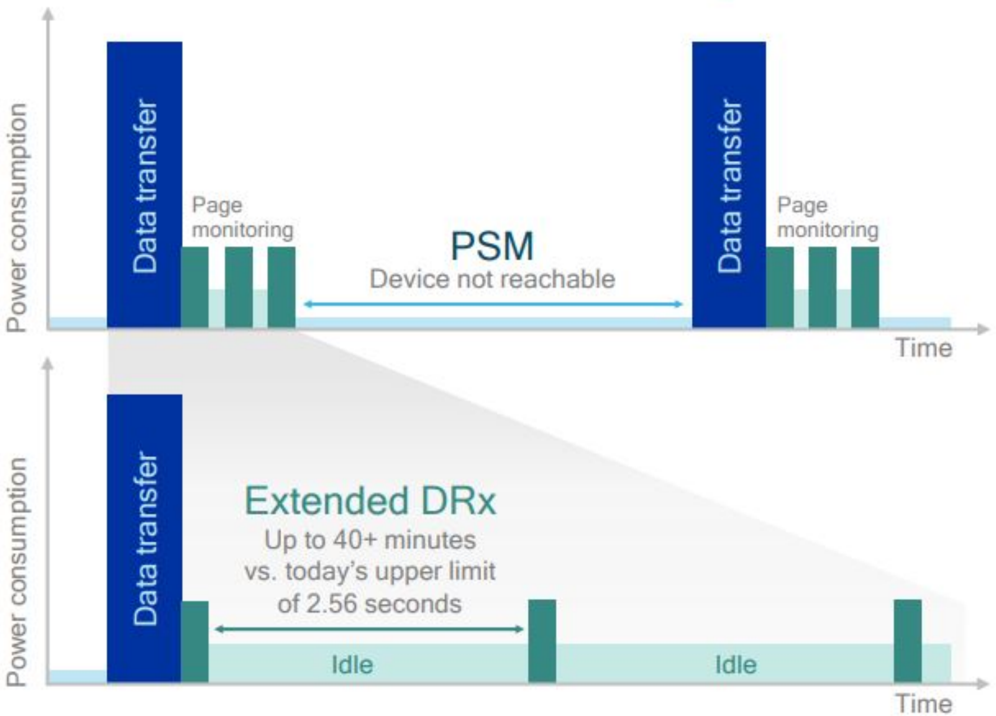
- A study cooperated by Deutsche Telekom summarizes the power consumptions of different LPWAN Technologies, namely LoRaWAN, Sigfox, NB-IoT, Weightless.



https://www.linkedin.com/pulse/nb-iot-versus-other-lpwan-technologies-harald-naumann/

Low power operation modes of NB-IoT

- NB-IoT improves power comsumption by operation modes allowing device to wake up per need basis:
  - Power Saving Mode (PSM)
  - Extended Discontinous Receive (eDRx)



https://www.qualcomm.com/documents/leading-lte-iot-evolution-connect-massive-internet-things

Low power operation modes of NB-IoT

- **Power Saving Mode** (PSM) eliminates page monitoring between data transmissions for device originated or scheduled applications, **e.g.** smart metering, environmental monitoring.
  - Device is in an unreachable state in this mode.

- **Extended Discontinous Receive** (eDRx) extends time between monitoring for network messages for device-terminated applications, **e.g.** object tracking, smart grid
  - Device is in an idle mode between paging messages.

NB-IoT General Deployment Overview

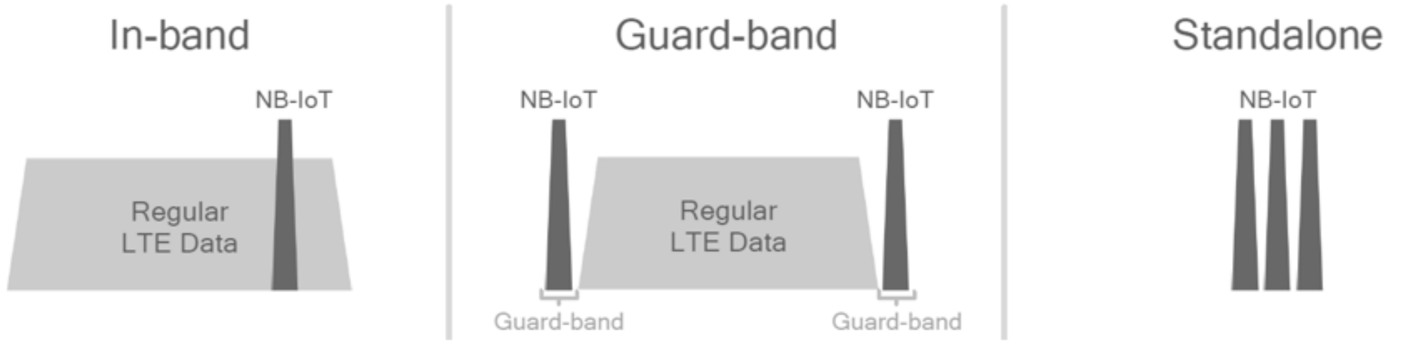
<table>
<tr><td rowspan="3">Vodafone: Spain, Ireland, Turkey, Italy, Czech Republic, Australia, Netherlands</td><td>KT-South Korea</td><td rowspan="2">Deutsche Telekom: Germany, Austria, Netherlands</td><td rowspan="3">China Telecom, China Unicom, China Mobile-China</td></tr>
<tr><td>M1 Singapour</td></tr>
<tr><td>Telecom Italia-Italy</td><td>Telia-Norway</td></tr>
</table>

Table: Operators deployed NB-IoT in their networks

- T-Mobile US offers a NB-IoT plan that will cost an enterprise $6 a year per device up to 12MB.
  https://newsroom.t-mobile.com/news-and-blogs/narrowband-iot.htm
- A global deployment map of IoT networks:
  https://www.digitalkeys.io/nb-iot-network

Deployment Options

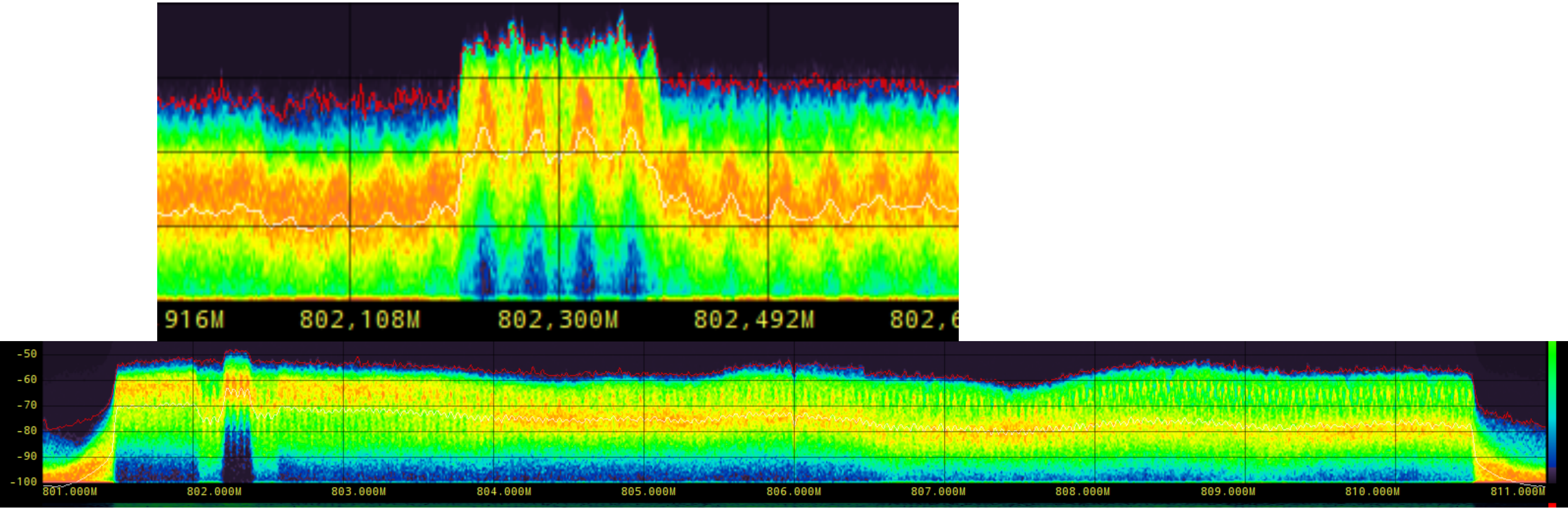
- NB-IoT can be deployed in 3 different ways;
  - Stand alone: utilizing stand-alone 200 kHz carrier in GSM spectrum
  - Guard band: utilizing unused resource blocks within an LTE carrier guard-band.
  - In band: utilizing single resource block (180kHz) within an LTE carrier. *Currently, this option is deployed in Netherlands, in frequency band 20 (800 MHz band).



https://www.semiconductorstore.com/blog/2017/From-Digi-International-Introducing-NB-IoT-Technologies-for-Cellular-IoT/2469

NB-IoT Spectrum

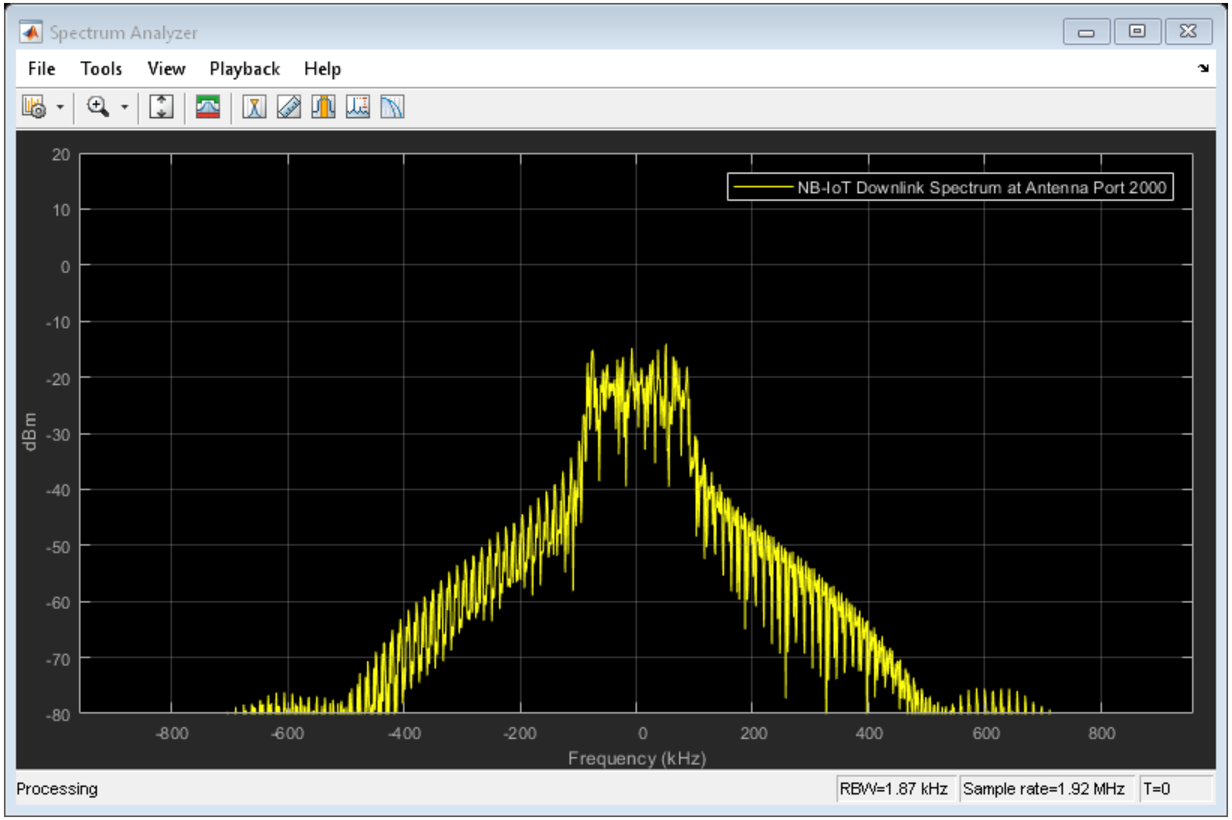
- Currently in band deployment is used by operators.
- In the figure, waterfall (power spectral density) plot of LTE Spectrum is illustated, with one resource block in use by NB-IoT.



http://www.softwareradiosystems.com/news_2017_05_08_nb-iot/

Matlab Example

- Matlab has an example in LTE toolbox for NB-IoT waveform generation, block error rate calculation of NPDSCH channel.



https://nl.mathworks.com/help/lte/examples/nb-iot-npdsch-block-error-rate-simulation-and-waveform-generation.html

NB-IoT Key Parameters

Duplex mode	Half Duplex
Modulation Schemes	Downlink: QPSK
	Uplink: Single Tone: π/4-QPSK, π/2-BPSK Multi Tone: QPSK
Data Rate	~25 kbps in DL and ~64 kbps in UL
Error Correction	Cyclic Redundancy Check (CRC) Repetition of certain channels (NPDSCH) *(increases coverage area)
Synchonization	LTE and NB-IoT synchronization channels
Rate Matching	Yes
Channel coding	Turbo Coding

NB-IoT Key Parameters

Rate Matching	Yes
Channel coding	Turbo Coding

- **Turbo codes** are error-correcting codes with performance closely approaches the channel capacity, a theoretical maximum for the code rate.
- The main task of the **rate-matching** is to extract the exact set of bits to be transmitted within a given TTI.
- The **rate-matching** for **Turbo coded** transport channels is defined for each code block, with three basic steps: interleaver, bit collection and bit selection.
- https://en.wikipedia.org/wiki/Turbo_code

NB-IoT Channels

- For the downlink, three physical channels
  - NPBCH, NPDCCH, NPDSCH: broadcast channel, downlink control channel, downlink shared channel

    and two physical signals
  - NRS, Narrowband Reference Signal
  - NPSS and NSSS, Primary and Secondary Synchronization Signals

- For the uplink, the two physical channels
  - NPUSCH, NPRACH: uplink shared channel, random access channel

    and the
  - DMRS, Demodulation Reference Signal

    are defined.

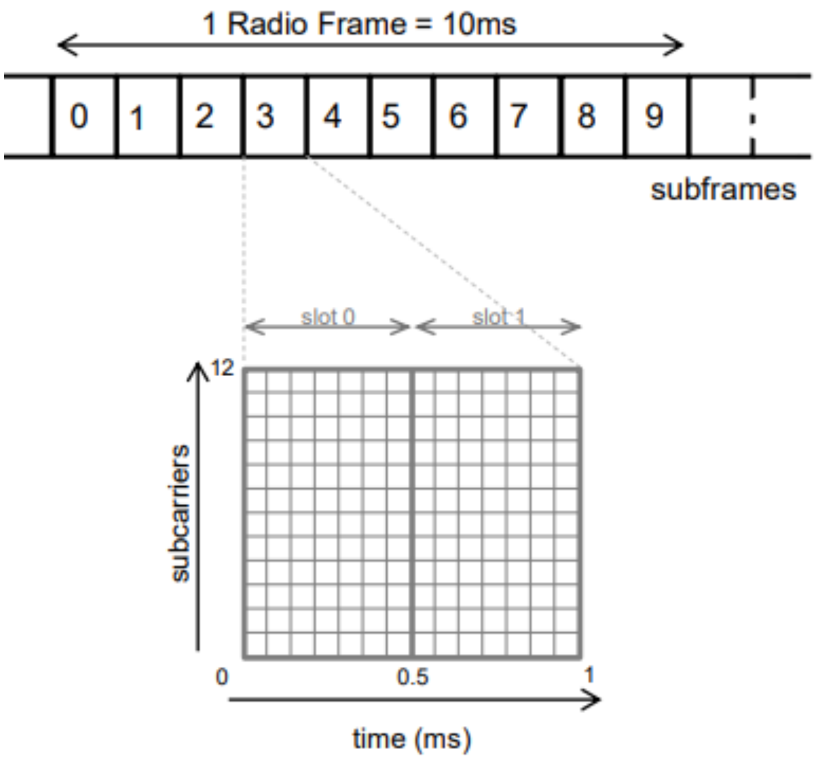
NB-IoT Channels

- NB-IoT physical channels are evolved from existing LTE channels.
- Then, NB-IoT physical channels are mapped to transport channels of LTE.
- New physical synchronization signals are defined for NB-IoT, compatible with its resource block size.
- Synchronization signals are used to detect start and end of frames, and the cell specific parameters.
- Each device has a specific ID, which they check for in the signal before they decode the channel carrying information.

Downlink Scheme

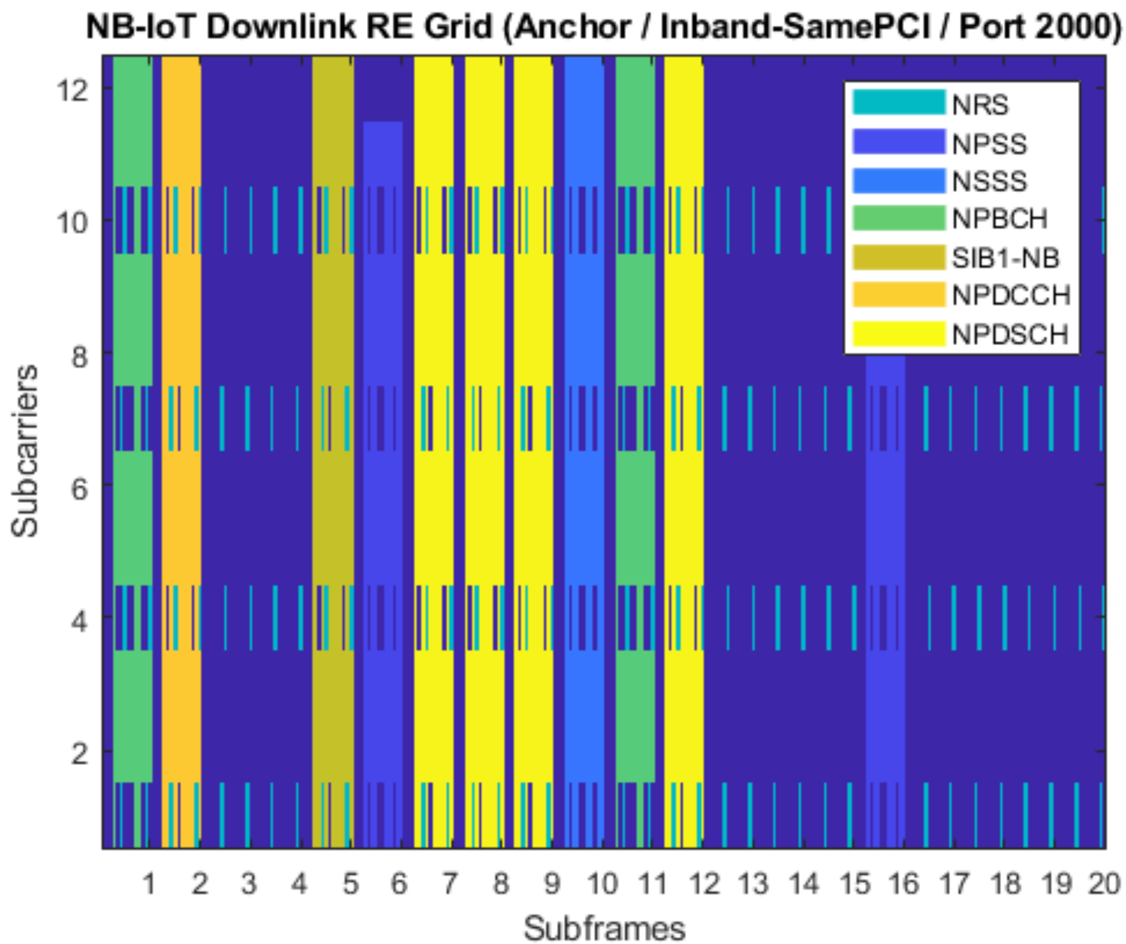
- In downlink frame, physical signals and channels are prelocated in a frame-slot-symbol base.

- Same numerology as LTE (co-existence with LTE)
- BW: 180 kHz = 12 subcarriers separated 15 kHz
- Equivalent to 1 LTE Physical Resource Block
- Durations: 1 Frame = 10 subframes = 10 ms
- 1 subframe = 2 slots (1ms)
- 1 slot = 0.5ms (7 OFDM symbols)
- 1 Hyperframe = 1024 x 1024 radio frames (~ 3hours)



https://www.keysight.com/upload/cmc_upload/All/20170612-A4-JianHuaWu-updated.pdf

Downlink Channels Grid



https://nl.mathworks.com/help/lte/examples/nb-iot-downlink-waveform-generation.html

Uplink Scheme

- Single Tone: (Mandatory)

To provide capacity in signal-strength-limited scenarios

  - Number of subcarriers: 1
  - Subcarrier spacing: 15 kHz or 3.75 kHz (via Random Access)
  - Slot duration: 0.5 ms (15 kHz) or 2 ms (3.75 kHz)

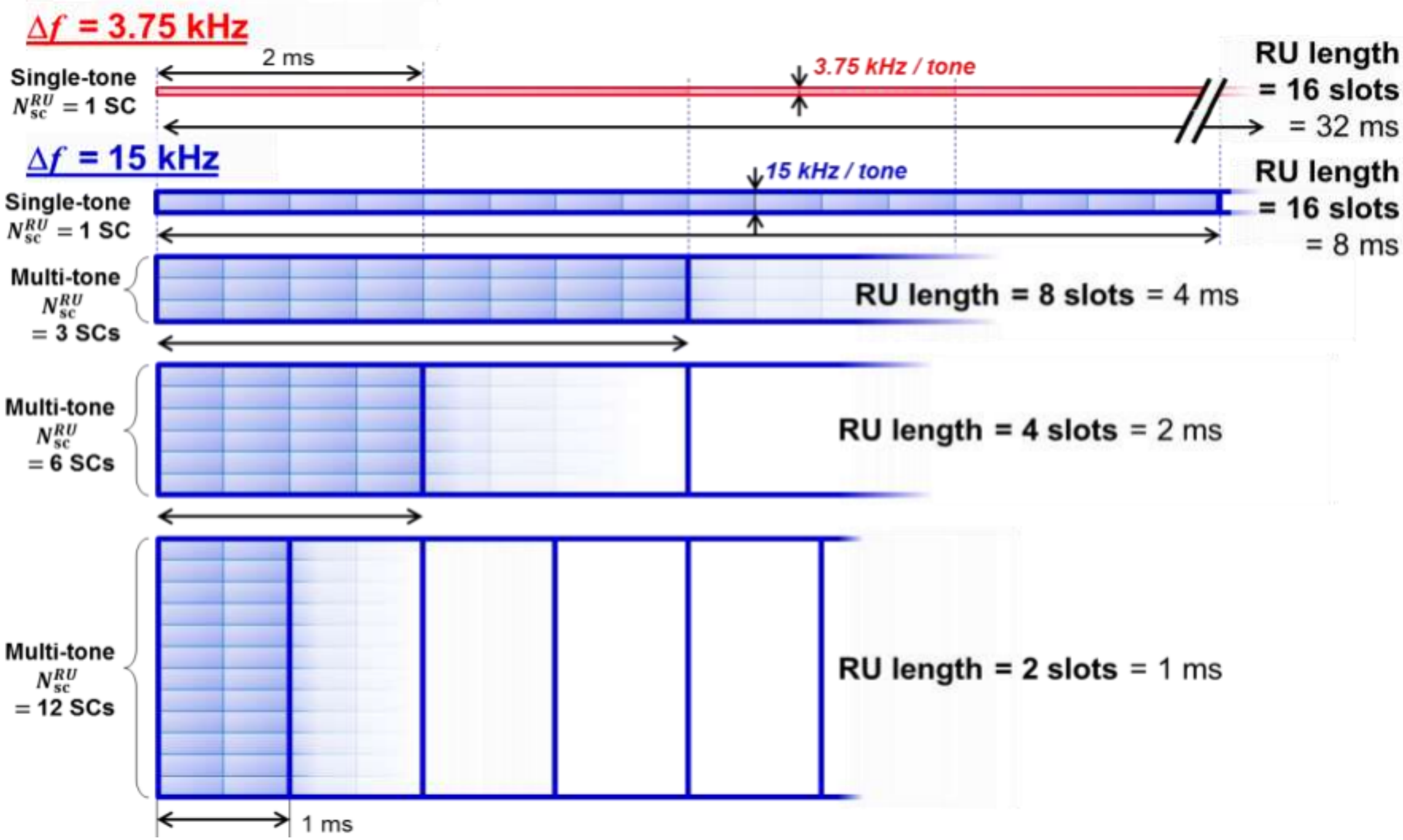
- Multi Tone: (Optional)

To provide higher data rates for devices in normal coverage

  - Number of subcarriers: 3, 6 or 12 signalled via DCI
  - Subcarrier spacing: 15 kHz
  - Slot duration: 0.5 ms

https://www.keysight.com/upload/cmc_upload/All/20170612-A4-JianHuaWu-updated.pdf

Uplink Scheme



https://www.keysight.com/upload/cmc_upload/All/20170612-A4-JianHuaWu-updated.pdf

Matlab Example

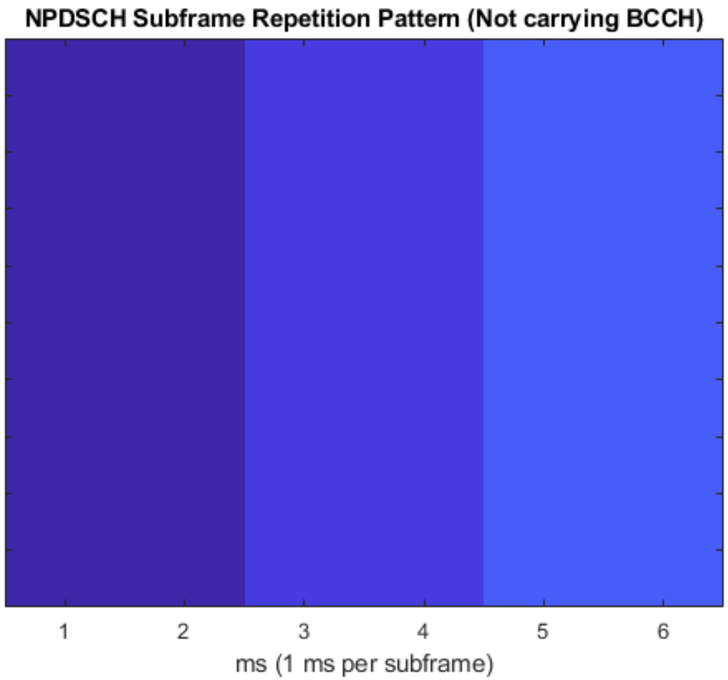
- The variable «NPDSCHScheme» indicates
  - If NPDSCH transmission carries the
  - ✓ SystemInformationBlockType1-NB (SIB1-NB) or not
  - ✓ Broadcast control channel (BCCH) or not.

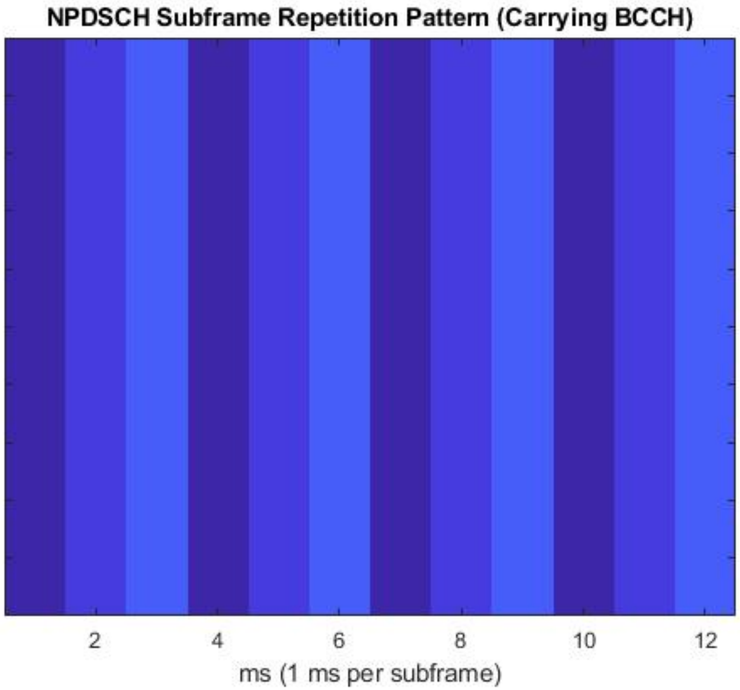
- The presence of SIB1-NB in the NPDSCH affects the number of NPDSCH repetitions and the transport block size (TBS)

- The presence of BCCH in the NPDSCH has an effect in the NPDSCH repetition pattern and the scrambling sequence generation

Matlab Example

- Repetition pattern in different cases, in terms of carrying control and system information.





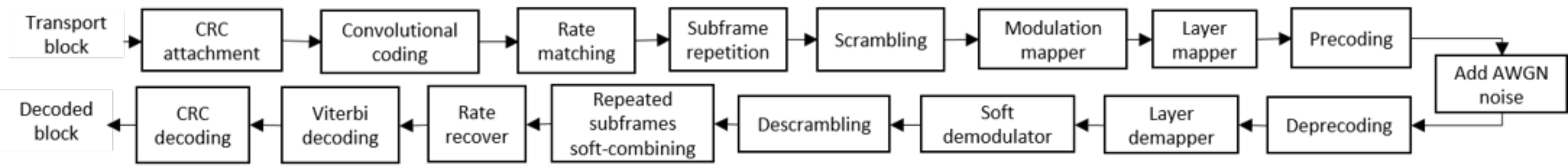
https://nl.mathworks.com/help/lte/examples/nb-iot-npdsch-block-error-rate-simulation-and-waveform-generation.html

Matlab Example

Block Error Rate Simulation Loop

NB-IoT NPDSCH link level simulation and plot BLER results.

- A random stream of bits, length of a transport block
- CRC encoding
- Convolutional encoding and rate matching -> NPDSCH bits
- Subframe repetition pattern.
- Scrambling, modulation, layer mapping and precoding -> complex NPDSCH symbols.
- AWGN is added

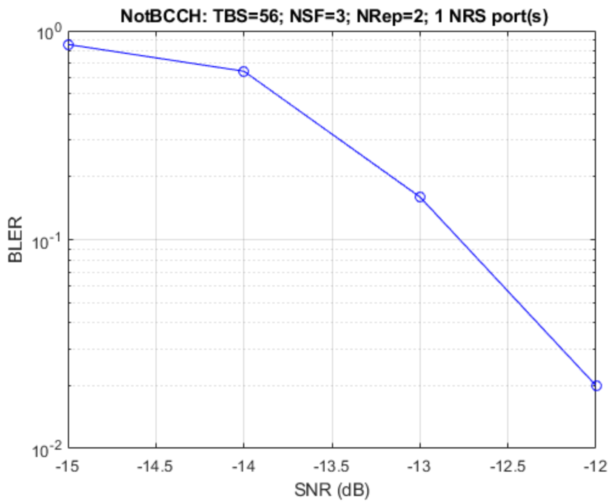


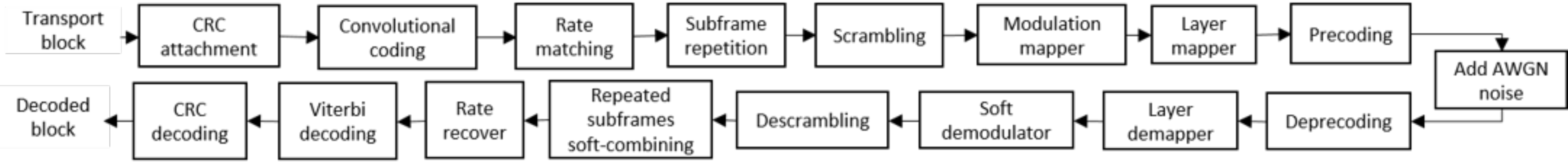
https://nl.mathworks.com/help/lte/examples/nb-iot-npdsch-block-error-rate-simulation-and-waveform-generation.html

Matlab Example

Block Error Rate Simulation Loop

- After de-scrambling, the repetitive subframes are soft-combined before rate recover.
- The transport block error rate is calculated for each SNR point.



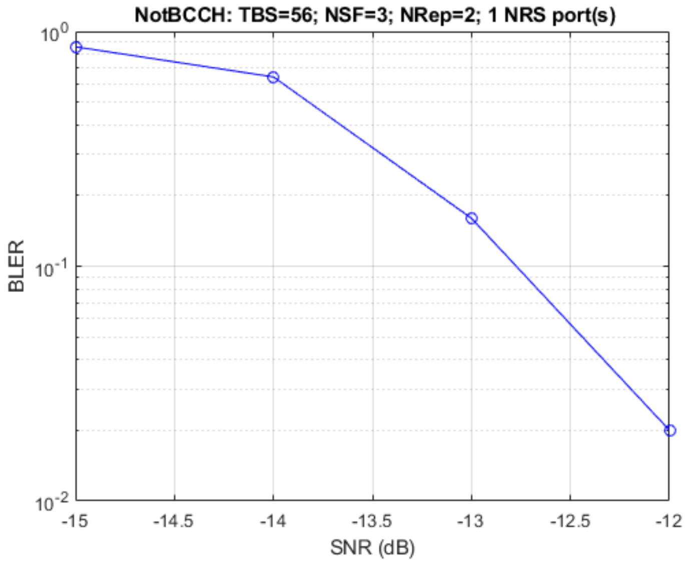


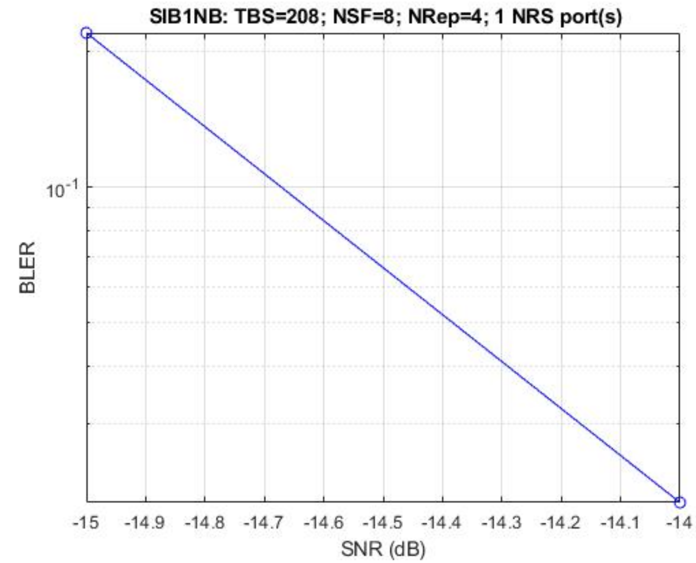
https://nl.mathworks.com/help/lte/examples/nb-iot-npdsch-block-error-rate-simulation-and-waveform-generation.html

Matlab Example

Block Error Rates

- Repeating the channels lowers the error rate experienced, eventually leads to a better coverage as mentioned in the specifications.





https://nl.mathworks.com/help/lte/examples/nb-iot-npdsch-block-error-rate-simulation-and-waveform-generation.html

Current developments

- Besides the works of corperations on NB-IoT deployment, small start-ups are working on developing tools for better utilization of NB-IoT modules.

- There are available evaluation boards for NB-IoT, ready to use after purchasing a simcard, as well as only module options.

- The pricing and availability of evaluation boards are varying ~(from 80 to 325 €).

- https://www.codico.com/shop/en/bc95gjate-a-02-std.html

- https://www.sierrawireless.com/products-and-solutions/embedded-solutions/products/hl7800/

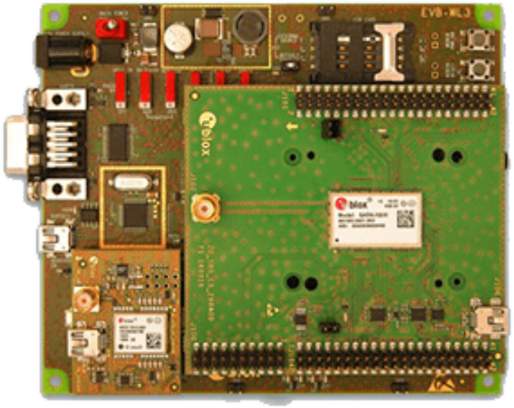


Figure: https://www.u-blox.com/en/product/evk-n2

Current developments

- Another development is from a Dutch Startup, named SodaQ, aiming to produce NB-IoT Shields for Arduino by June 2018.
- T-Mobile in Netherlands is supporting this initiative, by offering a free sim card and a year of free connectivity to the customers of this product.
- The pre-order prices are varying for different bundles, starting from 45€.

SODAQ
AllThingsTalk
ublox

https://www.kickstarter.com/projects/sodaq/the-first-nb-iot-shield-for-arduino-supported-by-t