MAC LAYER FOR IOT LPWA NETWORKS

REPORT – 5 ISS INSA TOULOUSE

The purpose of this report is to show the knowledge/skills that I have acquired on MAC layer and its functionality in IoT LPWA networks.

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Introduction

In comparison with traditional computer & telecom networks, the nature of the IoT network and the IoT end-devices are quite different and so are their needs and attributes. Some of the important requirements in IoT network are

- scalability to support thousands of devices within a cell area
- reducing the power consumption and extending the battery life duration for end-devices
- longer range

To support these unique requirements, the industry players & standardization bodies have developed Low Power Wide Area network (LPWA) based technologies as found in below **table-1**. In this report, I will be focussing to investigate on the MAC layer technologies in each of the LPWAN IoT networks.

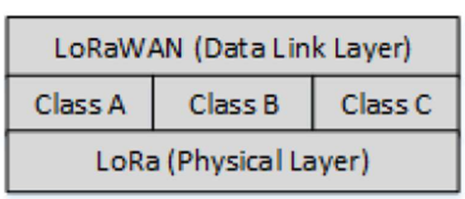
Category	LPWAN Technologies	MAC Layer	Bidirectional	Data rate
Cellular-based	NB-IoT	DL: OFDMA UL: SC-FDMA	**Yes** Uplink & downlink	65 kb/s
Proprietary	LoRA-Class A	ALOHA	**Yes** Limited downlink	50 Kbps
	LoRA-Class B	Slotted ALOHA	**Yes** Downlink is better	50 Kbps
	LoRA-Class C	ALOHA	**Yes** Downlink is good	50 Kbps

Table-1 Comparison of IoT networks

The cellular based LPWA technologies have the advantage as the cellular infrastructure is readily available in most of the countries. Whereas, the proprietary technologies need to adapt for certain specific use-cases.

LoRAWAN MAC

The MAC layer or Data Link layer in LoRAWAN enables the end user-devices to communicate with one or more LoRA gateways in both directions – uplink and downlink. As found from **Figure-1**, the LoRaWAN is classified into 2 types as Class A, Class B, Class C. The class can be chosen based on the use-case requirements.



As found from table-1, Class A is more suitable for deployments that are very sensitive on power requirements. Because, in Class-A, the End-devices can receive any data only after a transmission. That too, only for 2 short downlink windows as found from **Figure-2**.

Figure-1 LoRaWAN MAC layer

Therefore, Class-A is suitable for applications that doesn't require active use of downlink. In addition to the 2 short downlink windows, Class-B allows to schedule more windows for receiving data. This makes Class-B type MAC to be more suitable for deployments which require active use of downlink. In Class-C, the receiving window will always be open even when there is no transmitting of data. This is suitable for applications which require more active use of downlink.

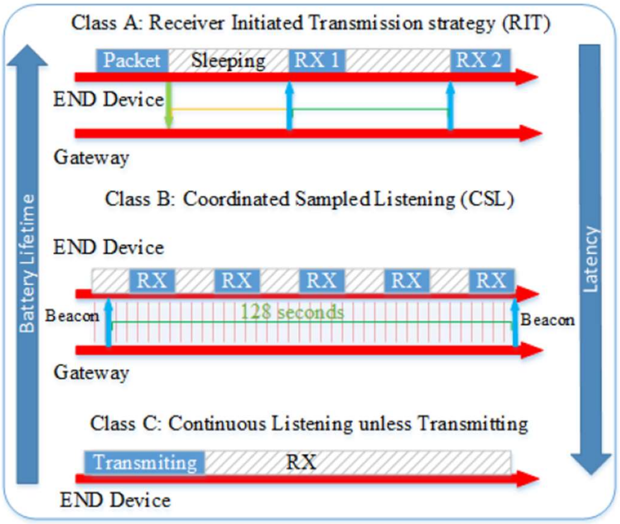


Figure-2 LoRaWAN MAC functions

In summary, as found from figure-2, the MAC layer choice determines the 'battery lifetime' and 'latency'. Therefore, based on the application/use-case requirements, the MAC layer choice is made. Class-A is more power efficient but the latency is high. It can be suitable for telemetry & tracking applications. Whereas, Class-C consumes high power but the latency is low which makes it suitable for real time applications.

NB-IoT

The NB-IoT technology is a 3GPP defined cellular technology which has the specifications **selectively** derived from the LTE standards to make it suitable for deploying for Low power applications.

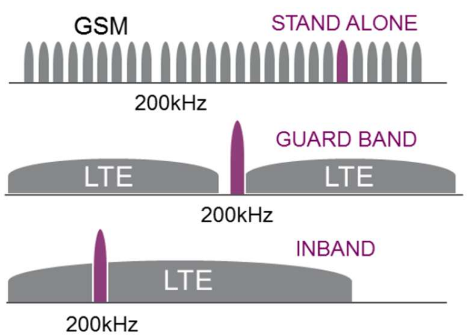


Figure-3 NB-IoT transmission modes

The MAC layer in NB-IoT supports both uplink and downlink as mentioned in **table-1.** While using the GSM bands, the NB-IoT functions as 'standalone' as found from Figure-3. While using the LTE bands, the MAC layer helps in 'Guard band' or 'Inband' modes for uplink and downlink. Referring to table-2, the channels seen in the table and the messages are used for resource mapping.

Channel		Usage
UL	Narrowband Physical Uplink Shared Channel (NPUSCH)	Uplink dedicated data
	Narrowband Physical Random Access Channel (NPRACH)	Random access
DL	Narrowband Physical Downlink Control Channel (NPDCCH)	Uplink and downlink scheduling information
	Narrowband Physical Downlink Shared Channel (NPDSCH)	Downlink dedicated and common data
	Narrowband Physical Broadcast Channel (NPBCH)	Master information for system access
	Narrowband Synchronization Signal (NPSS/NSSS)	Time and frequency synchronization

Table-2 NB-IoT MAC Layer resource mapping

These channels are used for uplink and downlink resource mapping by the MAC layer in NB-IoT. NPSS and NSSS are used for efficient cell searching and they are transmitted every 10 ms and 20 ms respectively. In the NBBCH channel, the Master Information Block (MIB) is transmitted every 80 ms once for 8 times.

The NBDCCH is used for carrying the downlink messages (paging, system control) from the eNodeB or BTS to the end-device. The NBRACH is used by the End-device for cell-accessing where a preamble is transmitted. NBUSCH is used to carry the uplink messages and send HARQ Ack/Nack. Single-tone and multi-tone transmissions and BPSK/QPSK modulations are supported.

NB-IoT MAC functions

Accessing the cell

When a End-device has data to transmit (Uplink) to the cell-npde or the eNodeB, then, it will search appropriate frequency bands, then, read the SIB information, and will start the Random access procedure.

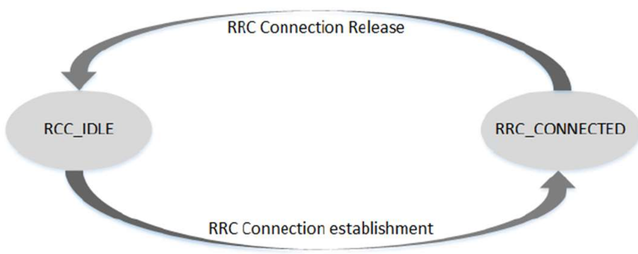


Figure-4 End-device status

As found from Figure-4, a End-device has 2 states: RCC_IDLE and RRC_CONNECTED.

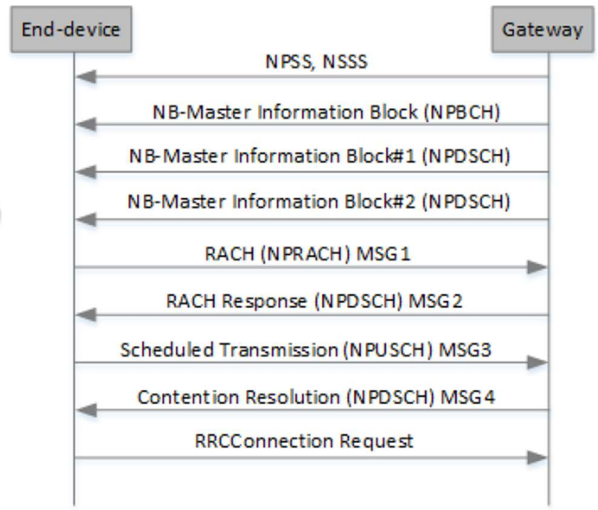


Figure-5 Connection Setup

As found in **Figure-5** the connection setup begins and the ED receives the NB Physical Cell ID from the cell which is decoded by the ED to get the NB-MIB which includes SIB-1-NB. Then, the ED decodes SIB-NB to learn the cell-access parameters such as PLMNID, TA code, cell identity & cell status and cell selection information like the minimum receiver level. Followed by, ED then decodes SIB-2-NB and finds the RACH configuration information required for uplink synchronization. ED then sends the preamble to the gateway or cell/eNodeB and goes on to complete the RACH procedure which tells that the ED wants to connect to the network.

Mobility

It is the function of the MAC layer to handle the connection transfer to a new gateway or eNode when the ED moves/in mobility.

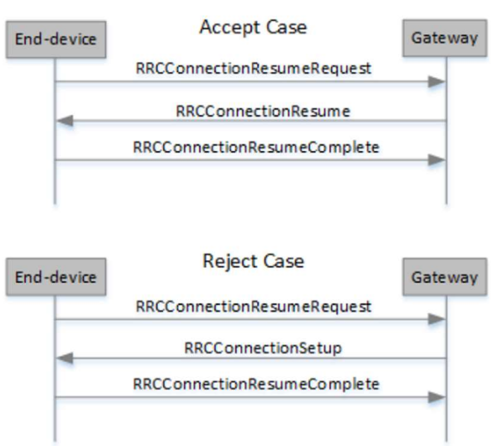


Figure-6 Connection resume process

Whenever the ED loses the connection with the gateway, ED will change to 'RCC_IDLE' state to reselect a new gateway/eNodeB. The setup time will be 10 ms or less than that based on the mode – standalone, in-band or guard band. Eventually, the gateway releases the connection and sends the Access stratum (AS) to ED for storing it as it will be required for resuming the connection faster as can be found in **figure-6**. There are 2 cases - Accept & Reject case. In Accept case, the gateway switches back to the same connection. In reject case, the ED has to repeat the connection setup procedure.

Direction	Legacy Service Request	RRC Connection Resume	Control Plane Data Transmission
UL	Preamble		
DL	Random Access Response		
UL	RRC Connection Request	RRC Connection Resume Request	RRC Connection Request
DL	RRC Connection Setup	RRC Connection Resume	RRC Connection Setup
UL	RRC Connection Setup Complete	RRC Connection Resume Complete	RRC Connection Setup Complete
DL	Security Mode Command	-	-
UL	Security Mode Complete	-	-
DL	RRC Connection Reconfiguration	-	-
UL	RRC Connection Reconfiguration Complete	-	-
Total # of messages	9	5	5

Table-3 NB-IoT MAC Signalling Comparison

Referring to the figure-6, when the ED gives connection resume request to the gateway/eNodeB, and the request is accepted, the cost is 5 messages. In the cases where the gateway rejects the resume request, the ED will be repeating the connection request which costs in total 9 messages.

Therefore, in the uplink scenarios whereby the ED wakes up from sleep, the NB-IoT MAC layer assists to resume the connection if it was established. Otherwise, it helps the ED in setting up the connection. Once the connection is established, ED starts transmitting the data. In the downlink scenarios, whereby the gateway/eNodeB wants to communicate to ED about the change in system info or wants to do a connection setup, it uses a paging method to trigger an 'RRC connection'. Thus, in NB-IoT standard, a End-device can move between different NB-IoT gateways/eNodeB's.

Conclusion

In this report work, I explored the IoT LPWAN network technologies that are cellular based and proprietary. I chose NB-IoT from cellular and LoRA from proprietary technologies for further investigation and comparison.

From the MAC implementation in NB-IoT, I was able to understand how the MAC layer works in IoT network to perform connection setup, connection resume and mobility. In my further study on this subject, I will be exploring the MAC layer in other technologies such as Sigfox, eMTC.

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