# 5G Heterogeneous Communication Architectures for the Internet of Thing

Fabian Schulz

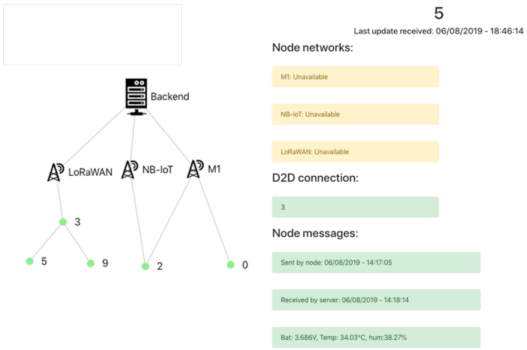
Professor : Alcherio Martinoli
Supervisors : Alexandru Rusu (Swisscom SA), Anwar Quraishi

The internet of things is growing at an incredible rate, to satisfy this demand in terms of connectivity, multiple novel network technologies have been developed. Those type of networks are called Low Power Wide Area Networks (LPWAN) and are adapted to the needs of those millions of low powered connected devices. In this work, three such networks: LTE cat-M1, NB-IoT and LoRaWAN have been characterized; presenting their bandwidths, latencies and precise power consumptions for end-devices in a real-world scenario using live networks already deployed by Swisscom. Each of those networks has their own advantage and use case: LoRaWAN for tiny payloads sent infrequently, NB-IoT for larger payloads when M1 connectivity is poor and M1 for large payloads or messages which require short latencies. The results below were gathered using custom hardware designed during this project.

| Network | Payload [bytes] | Cons [mAh] | Speed [kbit/s] | RTT [s] |
|---|---|---|---|---|
| M1 | 100 | 6.29 | 12 | 0.13 |
| NB | 100 | 14.34 | 2.6 | 0.61 |
| M1 | 1000 | 14.5 | 50 | 0.31 |
| NB | 1000 | 29.5 | 13 | 1.26 |
| LoRaWAN | 34 | 1.32 | SF7 | 1.53 |
| LoRaWAN | 34 | 20-40 | SF12 | 3-7 |
| D2D send | 34 | 0.77 | SF7 | 0.23 |
| D2D receive | 34 | 0.74 | SF7 | 0.19 |

*Mean values for message transmission and response*

Using this precise characterization, we could design a heterogeneous network combining all three of the above-mentioned networks. Each node is able to communicate using all three network technologies and chooses itself which one to use depending on the quality of service desired, the payload size, the remaining battery power and the signal strength of each network at the node's location. To further improve our novel network architecture, we have implemented a direct device to device (D2D) communication protocol using LoRa, which is the LoRaWAN physical layer. An Orchestrator which implements the Medium Access Control (MAC) for the LoRa D2D and LoRaWAN has also been developed and implemented. Nodes not able to connect to any network directly or with very low power consumption requirements can now use the D2D communication to connect to another node which then relays the payloads to the cloud. The current network topology, connectivity information about each node and the messages transmitted can then be viewed in an online control center depicted below.




*Cloud control center to display the current network topology and connectivity information of each node*

The hardware and software developed during this project can now be used to test the connectivity of the presented networks at different locations, this can be useful before planning and implementing a new IoT solution. This testing can be done on premise using our testbench, similar to a tablet, or fully controlled from the cloud using the online interface of the testbench. Thanks to the modular nature of our hardware, new modems can easily be integrated and tested. The heterogeneous network developed during this thesis is a proof of concept implementing a very simple medium access control and message forwarding protocol. Nevertheless, it shows the huge potential of such a heterogeneous network combining D2D communication together with multiple LPWAN networks. We hope this thesis encourages further research in this domain and that one day every low powered device can find connectivity autonomously without any configuration.