Poster Abstract: Power Consumption analysis of NB-IoT for uplink data transmission

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***Abstract*— This paper investigates the energy consumed during the transmission of data packets of different sizes using LTE Narrowband Internet-of-Things (NB-IoT) cellular technology. In this work, the power consumption measurements were recorded and analyzed. The analysis of the measurements led us to formulate a hypothesis where we assumed the first peak in the measurements while transmitting packets to be the radio connection to the base station and some consecutive peaks to be the actual data transmission and the last peak to be the acknowledgment for the packet. The results of the experiment did support our hypothesis to some extend but as a future work with better experimental setup would helps us prove our hypothesis to be 100 percent true. The results shows that the energy consumption as well as the time required for sending data increases with increase in packet size.**

I. INTRODUCTION

The NB-Iot also known as Cat-NB1 is a cellular LPWAN technology especially designed for simple IoT devices. NB-IoT can be used in applications where power consumption is crucial and extended coverage with deep indoor penetration is required. As we know for every TCP packets sent over the network, the receiver sends Acknowledgement (ACK) on successful reception of the packets. Three main experiments were conducted and these experiments helped us to understand and visualize the TCP packet transmission and ACK. By obtaining the power consumption measurement trace from these experiments, we can actually visualize how the Data link layer in order to reduce bit transmission errors, makes the sender break the input data up into data frames (typically, each data frame contains few bytes of data), transmit the frames sequentially and process the ACK sent back by the receiver. In other words, the measurements indicates that each packet received from the Network layer on the sender side is being divided into smaller data frames before the transmission where each frame is believed to be of certain buffer size.

In all the three experiments, the measurement trace followed the same pattern which led us to formulate a hypothesis where we assumed the first peak in the measurements while transmitting packets to be the radio connection to the base station and some consecutive peaks to be the actual data transmission where each peak represents a data frame and the last peak to be the acknowledgment for the packet. This hypothesis made sense to some extend by conducting experiments for sending packets of varying sizes and each experiment was conducted keeping certain goal in mind that will help us verify the hypothesis to be true. One experiment also helped us understand and visualize the TCP Segmentation of packets into smaller segments at the transport layer when the packet size was greater than Maximum segment Size (MSS) before reaching the data link layer and the method used in this experiment also helped us understand IP fragmentation happening across the network. In this work, the time required to send packets of different sizes is also estimated.

II. SCOPE OF THE WORK

The main goal of the project is to visualize the transmission of TCP data packets and also to analyze the power consumption measurement trace and to investigate the energy consumed for transmitting packets of different sizes of data using LTE CAT-NB1.

III. METHODOLOGY

The expansion board with a FiPy which are the products from Pycom is used with an Otii Arc by Qoitech to collect the measurements and the NB-IOT SIM card used is from the mobile network operator Telia. To estimate the energy consumed, the Device Under Test (DUT) is attached to the network and connected to a base station. The voltage level is kept constant and the power drawn is measured during data transmission.

The Otii Arc supplies voltage to the FiPy (DUT) and senses the current drawn which can be recorded. By default, the WiFi and Bluetooth radios are turned on and we will have to manually turn off every single one to get the energy consumption down. The energy consumed during the transmission of 200 bytes of data with all the radio turned on was 1.5 mWh which was reduced to 8.086 µWh when sending the same amount of data by turning off all other radios not required for transmission. Hence the DUT is first made to turn off all other radios that are not needed for data transmission in order to reduce the power consumption. The modem is reset and correctly configured for carrier network. The DUT is then attached and connected to the network. The DUT will now have an active LTE connection.The data packets of varying size is sent after a successful TCP socket connection to a TCP server running on a local machine. The interval between two data packets was initialized to 10 seconds in order to separate the transmission of packets and to get a clear visualization in the measurement trace.

In each experiments, the packet is first sent to the base station (BS) and BS sends the packet to the server(tcp.ngrok.io) on the internet which forwards the

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packets through a secure tunnel to the server running on the local machine. After sending all the packets, the DUT goes into machine idle state. Using this method for the experiments helped us to confirm that the peaks for what we believe is the data transmission in the recording corresponds to the packets being sent. This architecture is shown in Fig. 1.

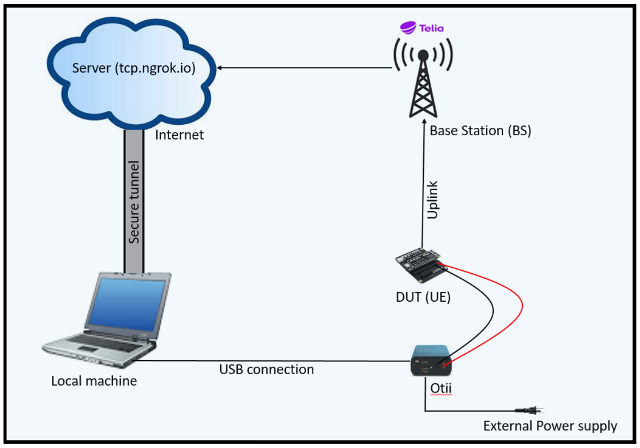

Fig. 1: Computer Network Architecture

IV. Experimental Setup and Hypothesis

The power measurements drawn from the experiments were analyzed and in the measurement trace, the curve for each packet transmission followed a similar pattern as shown in Fig. 2 which led us to formulate the hypothesis mentioned in the sub section below. The figure below show only a small portion of the entire measurement period approximately 400 ms in order to visualize the data transmission phase. The average power in the machine idle state is measured to be 62.5 mA which is in accordance with the FiPy specification (62.7 mA).

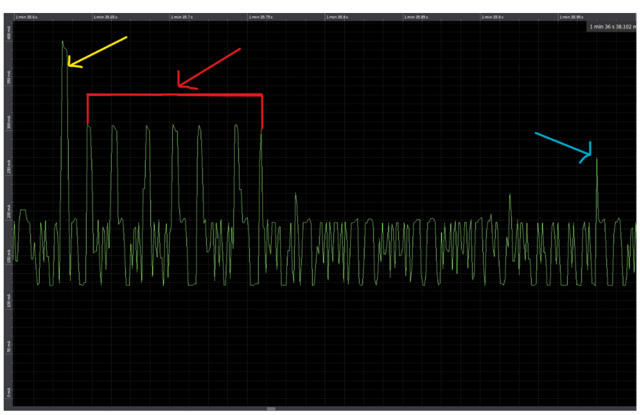

Fig. 2: This curve shows the transmission of a packet of size 700 Bytes

A. Hypothesis

After observing the curves during transmission of all the packets of varying size in all the experiments, we made an assumption as a starting point for further investigation that the first peak in the Fig. 2 pointed by the yellow arrow which has the maximum value of 401 mA is the energy required for the radio signal to reach the base station antenna to inform that it has some data packets to send and the next consecutive seven peaks pointed by red arrow is assumed to be the energy required for the actual data transmission and finally the last peak pointed by cyan arrow before two small peaks is assumed to be the energy required for the Acknowledgement (ACK) sent by the receiver on successful reception of the packets.

Experiment 1: In this experiment, 20 packets of data ranging from 1 byte to 20 bytes were sent by DUT and were received by the server running on the local machine. The time taken for the data transmission and for the ACK to reach DUT sent by the receiver is tabulated in Table I. The aim for conducting this experiment was to calculate the overhead required for sending a packet of any size of data.

Packet size (Bytes)	Data (ms)	ACK (ms)
1	4	171
2	4	180
3	4	171
4	4	176
5	4	180
6	4	171
7	4	166
8	4	167
9	4	171
10	4	171
11	4	180
12	5	170
13	4	181
14	4	215
15	4	171
16	5	179
17	5	171
18	5	180
19	5	179
20	5	180

TABLE I: The time required for sending packets of size from 1 byte to 20 bytes and for the ACK to come back.

Experiment 2: In this experiment, five trials were recorded by sending 10 packets of data ranging from 100 bytes to 1000 bytes and all the 10 packets was successfully received and acknowledged by the server. The average time is calculated from the five trials for the data transmission and for the ACK. The average time for data transmission and for ACK to reach the DUT sent by the receiver is tabulated in Table II and the average time required for the data transmission is plotted in Fig. 3.

The goal of this experiment was to draw conclusion for power consumed during uplink transmission and to calculate the time required for transmitting a packet of varying size ranging from 100 bytes to 1000 bytes.

Packet size (Bytes)	Data (ms)	ACK (ms)
100	20.2	170.8
200	37	169.8
300	40	171
400	57.4	170.6
500	70.2	172.4
600	94.6	170.4
700	111.6	197.2
800	132.2	149
900	135.2	180.2
1000	153.6	168.8

TABLE II: The time required for sending packets of different size and for the ACK to come back.

Data transmission time.PNG

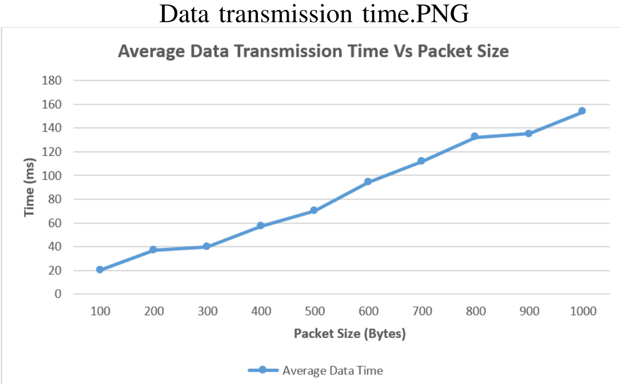

Fig. 3: This curve shows the average time taken to send packets of different size.

Experiment 3: In this experiment, 10 packets of data ranging from 1 KB to 10 KB were sent but the local server received more than 10 packets which indicates that the packets were fragmented across the network and sent. The packets started to divide into smaller packets for packet size starting from 2 KB to 10 KB which gives us an understanding that the Maximum Transmission Unit (MTU) of the network should be somewhere between 1000 bytes and 1500 bytes. The time taken for the data transmission is tabulated in Table III. The goal of this experiment was to visualize the segmentation of data by transport layer in the measurement trace and also the fragmentation of packets when the packet size was greater than MTU.

Packet size (KB)	Data (ms)
1	155
2	309
3	552
4	724
5	859
6	1030
7	1109
8	1382
9	1453
10	1648

TABLE III: The time required for sending packets of size 1 KB to 10 KB.

V. Results

This section presents the outcome of the experiments conducted. The power consumption measurement trace for all the three experiments followed a similar pattern which led us to formulate a Hypothesis as mentioned above. Comparing the results of experiment 1 with experiment 2, the power consumed for radio signalling base station and transmitting 1 byte of data is approximately proportional to 6.5 µWh and the power consumed for radio signalling base station and transmitting 100 bytes of data is 9.4 µWh. Whether we are sending 1 byte or 100 bytes of data (only payload), in both of these cases the TCP header will take 20 bytes and the IP header will also use 20 or more bytes and this means that at-least a minimum of 40 bytes are needed for the headers alone which is considered as the overhead. This ”overhead” can be clearly seen by comparing the power consumed for sending 1 byte and 100 bytes of data.

The experiment 3 results helped us understand and visualize segmentation of packets into smaller segments at the transport layer in the trace as shown in the Fig. 4 and the maximum segment size (MSS) is believed to be greater than 1000 bytes and less than 1500 bytes. The Fig. 4 shows the trace for sending a packet of 2 KB of data. In this trace, we can identify two segments and according to the hypothesis, we could see two higher peaks for radio signalling the base station and 18 peaks for data transmission and 2 peaks for ACK at the end of each segment. I expected the number of peaks for data transmission to be 18 since 1 KB has 9 peaks and 2 peaks for ACK’s due to TCP segmentation in which both of them turned out to be true. This figure clearly shows the TCP segmentation of data when the packet size becomes greater than MSS.

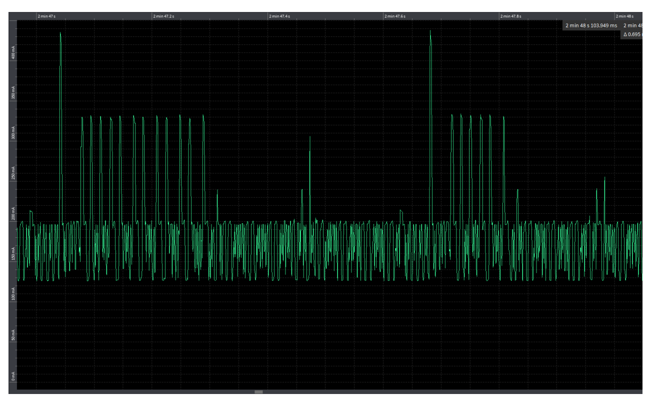

Fig. 4: This curve shows the transmission of a packet of size 2 KB

The IP fragmentation of TCP segments into smaller fragments was also seen in this experiments. The method used helped us verify that the Maximum transmission unit (MTU) to be to be greater than 1000 bytes and less than 1500 bytes. At first the MTU was believed to be 1500 bytes but the experiment results proved me wrong. The server running on the local machine would let us know the number packets received. In experiment 1, 20 packets were sent and the number of expected packets was 20 and the server received 20 packets and each packet size was in the range from 1 byte to 20 bytes. In experiment 2, 10 packets were sent and the number of expected packets was 10 and the server received 10 packets and each packet size was in the range from 100 bytes to 1000 bytes. In experiment 3, 10 packets were sent in the range from 1 KB to 10 KB. As the MTU was believed to be 1500 bytes, I expected the number of packets received by the server would be 40 due to fragmentation but the server received 85 packets in the first run and 83 packets in the second run of the same experiment. The number of packets received by the server started to increase when the packet size was 2 KB and greater. This clearly indicates that the value of MTU is in-between 1000 bytes and 1500 bytes but the exact value of MTU is still unknown in this experiment.

In all the three experiments, the round trip time (RTT) for the ACK is somewhat proportional to 171 ms and is almost being constant for different sizes of packets and the reason for being so is yet to be determined. In experiment 3, As the MTU was believed to be 1500 bytes, the numbers ACK seen in the trace did not match the expected number of ACK's as shown in Table IV. One possible reason for this could be delayed acknowledgement but future experiments would help us reason out.

Packet size (KB)	Expected ACK	ACK Seen
1	1	1
2	2	2
3	2	2
4	3	2
5	4	3
6	4	3
7	5	3
8	6	3
9	6	5
10	7	5

TABLE IV: The expected number of ACK's (if MTU was 1500 bytes) and the number of ACK's seen in the measurement trace .

A. Did the Data support the hypothesis?

Evidence 1: Based on our hypothesis, the part of the curve pointed by red arrow in the Fig. 2 was assumed to be the data transmission and in all the experiments, this time was calculated and tabulated.From experiment 2 and 3, we can see the time required for sending the packets increases with increase in packet size and this can be seen in their corresponding table.

Evidence 2: During the data transmission or what is assumed to be the data transmission from the hypothesis, the number of peaks were counted and in experiment 1, the number of peaks was one for all the 20 packets of size from 1 byte to 20 byte. The number of peaks is shown in Table V and in experiment 2, the number of peaks somewhat increases with increase in packet size as shown in Table V and finally in experiment 3, the number of peaks doubled for packets of size from 1 KB to 10 KB. since 1 KB has 9 peaks, I expected the number of peaks for 2 KB to be 18 , 3 KB to be 27 and so on and it turned out to be true. This is shown in Table VI

Evidence 3: In the measurement trace, it follows almost the same pattern for all the packets of different sizes which includes one peak for radio signal, one or more consecutive peaks depending on the packet size for the data transmission and one last peak before two small peaks for ACK. Based on the hypothesis, in all the experiments, for most of the packet size, the peak pointed by cyan arrow in Fig. 2 which represents ACK sent by the receiver for the packets, the time between the data transmission and ACK is approximately proportional to 171 ms.

Packet size (Bytes)	Number of peaks
1-20	1
100	2
200	2
300	3
400	4
500	5
600	6
700	7
800	8
900	8
1000	9

TABLE V: Shows the number of peaks for different packet size.

Packet size (KB)	Number of peaks
1	9
2	18
3	27
4	36
5	44
6	56
7	62
8	71
9	81
10	90

TABLE VI: Shows the number of peaks for different packet size.

B. Is the hypothesis true?

Each peak corresponds to a frame where the Data link layer divided the input data from the Network layer on sender side into smaller data frames before the transmission. Each peak or frame is believed to be of certain buffer size. I expected the number of peaks to be one for all the packets in range 1 byte to 20 bytes which turned out to be true and based on all the three evidences presented above, it may be true but we need more reasoning to confirm it because the number of peaks for a packet of size 100 bytes is 2, for a packet of size 900 bytes is 8 and for a packet of size 1000 bytes is 9. For each of these packets, I expected the number of peaks to be 1, 9 and 10 respectively but I don't have proper explanation why this is the case for these packets. I cannot assure, the number of bytes each peak corresponds to but in the future, experiments maybe conducted to get the accurate number of bytes each peak corresponds.

C. Power Consumption Analysis

we believe that our hypothesis to be impartially true given the evidences that we got from the data hence the energy required for sending the packets of different size is calculated by measuring the energy consumed for the peaks that are assumed to be the data transmission in all the five trials of experiment 2. The energy consumed for sending packets of size from 100 Bytes to 1000 Bytes by taking the average from the five trials is tabulated in the Table VII and plotted in the Fig. 5. We can see from the plotted graph that the energy consumption increases with increase in packet size.

Packet size (Bytes)	Power Consumed in μWh
100	3.858
200	8.086
300	11.04
400	15.48
500	19.12
600	24.78
700	29.54
800	34.48
900	35.40
1000	39.44

TABLE VII: The energy consumed for sending packets of different size.

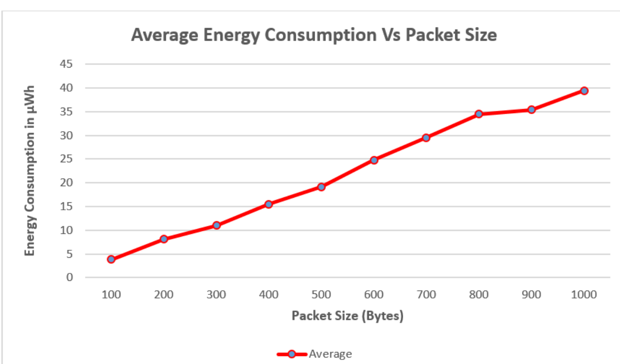

Fig. 5: This curve shows the energy consumed while sending packets of different size .

VI. Conclusions

This paper presents an evaluation study on the power consumption of LTE NB-IoT technology for packets of different sizes. There is an increase in the energy consumption as well as the time when the size of the packet is increased (Experiment 2 and Experiment 3). The comparison of results from experiment 1 and experiment 2 helped us understand the overhead (non-data) for sending a packet of any size. This analysis would suggest to use a better approach for sending data in order to reduce the power consumption and one possible way is to aggregate the data to be sent. This means sending 1 byte of data every time with certain time interval will actually consume more power because of the overhead so a better approach is to aggregate and send larger data packet of size for example 100 bytes. From experiment 3, the value of MTU is believed to be in-between 1000 bytes and 1500 bytes and hence the packets were fragmented into smaller packets across the network when sending packet size 2 KB and greater but future work with better experimental setup would help us get the exact MTU value of the network and the reason for number of ACK's to be less than the expected one. A future work also would be to perform experiments that fully supports the hypothesis.

VII. Learning Outcome

One of the main learning outcome in doing this project was the Visualization of interaction between different layers of the underlying OSI model especially the Transport layer, Network layer and Data Link layer. This project helped me understand and visualize something that I learned in theory and it was really surprising to actually see them in the power consumption measurement trace.

VIII. Acknowledgements

I would like to thank and express my gratitude to Professor Christian Rohner and Laura Marie Feeney for their valuable feedback and support throughout this project. I especially want to convey my heartfelt thanks to Laura Marie Feeney who had given me her complete support and guidance in times of difficulties and for all the time she spent without hesitation for helping me complete this project.

References

[1] Nurse JRC, Erola A, Agrafiotis I, Goldsmith M, Creese S. *Smart Insiders: Exploring the Threat from Insiders Using the Internet-of-Things.* 2015 Sept;p. 514.

[2] https://www.iotforall.com/what-is-cellular-iot/

[3] https://www.teliacompany.com/en/about-the-company/internet-of-things/nb-iot/