Evaluation of LoRa Performance in a City-wide Testbed: Experimentation Insights and Findings

NITLAB
NETWORK IMPLEMENTATION TESTBED LABORATORY

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CERTH

Air Quality Monitoring

- ✓ **Air pollution** is a crucial environmental situation that **drastically impacts on public health**, global environment, and worldwide economy

- ✓ Several **premature deaths** have reported from the **World Health Organization**, confirming that air pollution is responsible for that

- ✓ Long-term exposition to atmospheric pollutants cause health disorders such as respiratory, cardiovascular and cancerous diseases

- ✓ All the above highlight the urgent need for monitoring air pollution, towards providing meaningful data to **environmental protection agencies** to better understand the effects and protect the public

Air Quality Monitoring - Connectivity

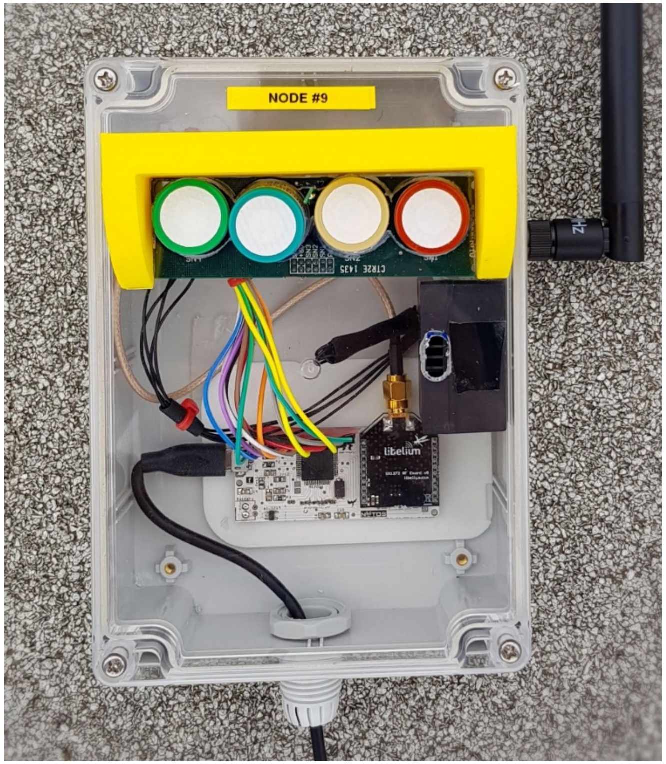
- ✓ A major problem in **city-scale**, **dense deployments** is the backbone connectivity
- ✓ Latest Ultra Long Range protocols are attractive solutions to enable backbone communication
- ✓ LoRa, LoRaWAN, SigFox, NB-IoT, etc.
- ✓ This direction is a key enabler as a step beyond the old-fashioned, atmospheric monitoring installations, usually deployed in a single location, incapable of delivering the appropriate spatial resolution

Outline

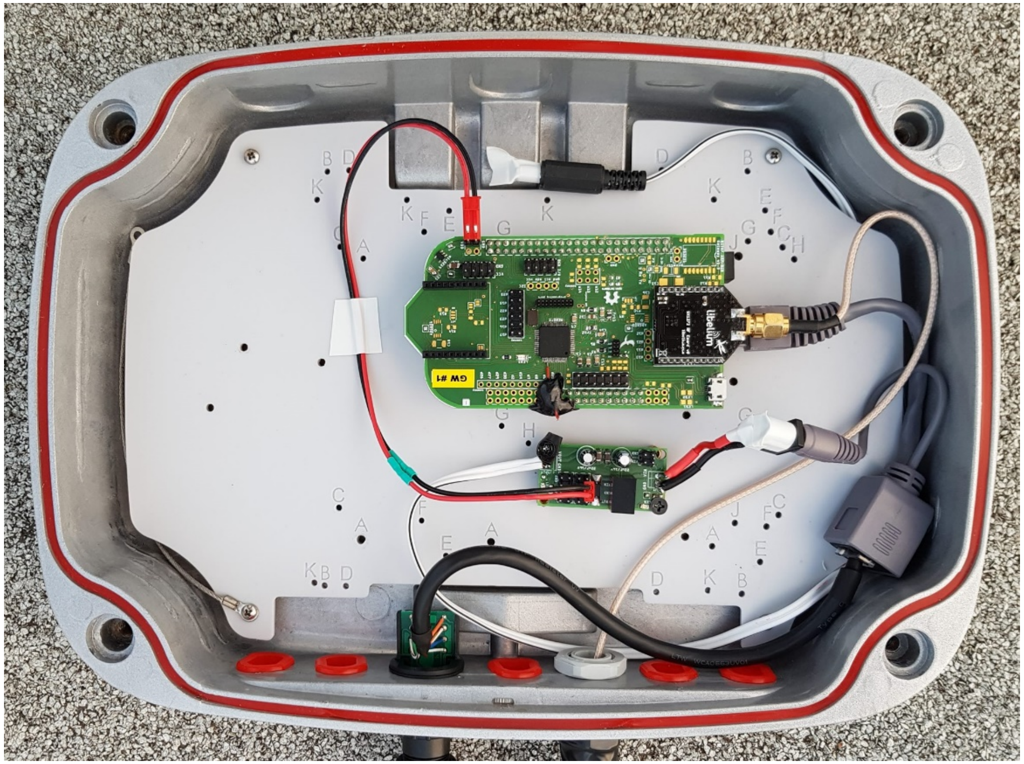
- ✓ Development and Deployment of Air Quality LoRa-enabled Testbed
- ✓ Software Toolkit to evaluate the performance of LoRa protocol
- ✓ LoRa Power Consumption Evaluation
- ✓ LoRa Communication Performance Evaluation

Air Quality Nodes

✓ Developed LoRa nodes:



Air Quality Monitoring
LoRa sensors



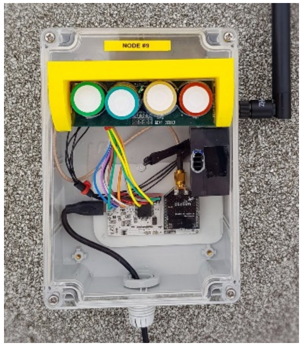
LoRa Gateway

Sensor Node's Components

- ✓ The sensor node consists of:

Gas Concentration Probes
(NO2, SO2, CO, NH3, O3)

By AlphaSense

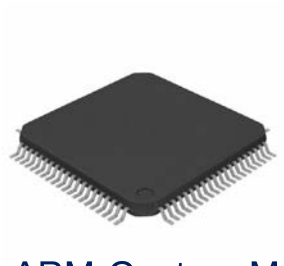


Sensor Node

PM2.5 dust particle concentrator
sensor

HPMA115S0 by Honeywell

SHTC3 Temp & Humidity
sensor by Sensirion

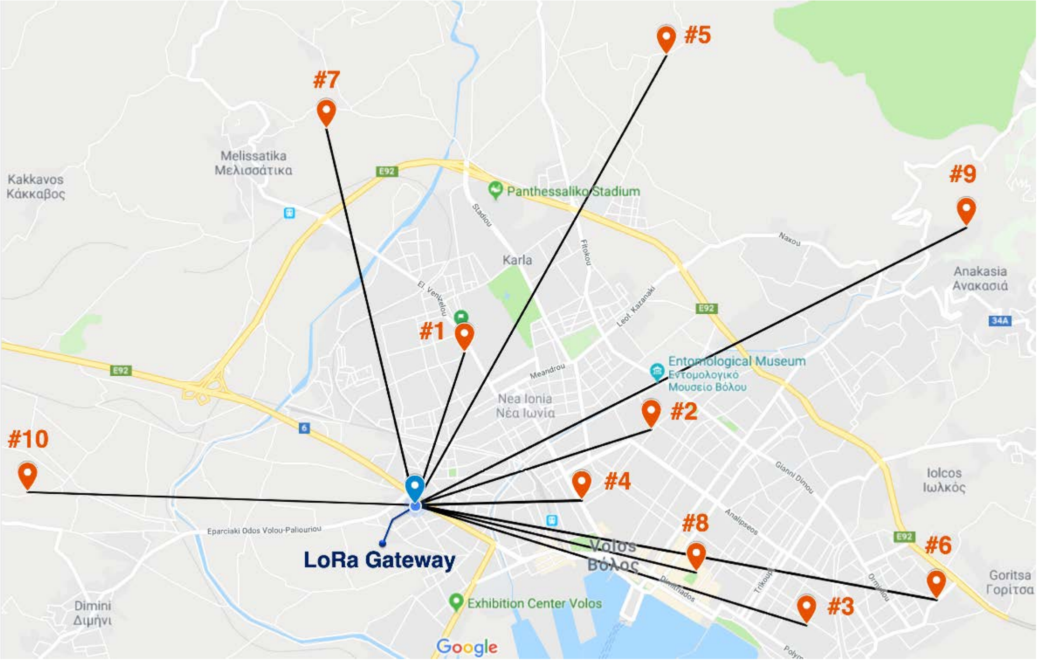


ARM Cortex-M4
by NXP

SX1272 LoRa chipset
by Semtech

Air Quality Nodes

✓ The nodes are scattered across the city of Volos, offering **wide range of wireless links** that differentiate in terms of communication **distance**, **elevation** difference and **LOS/NLOS** conditions



Deployment map in the city of Volos, Greece

Node #	Distance (km)	Altitude (m)	LOS
GW	-	23	-
1	1.3	43	no
2	1.98	30	no
3	3.25	32	no
4	1.33	25	no
5	4.12	179	yes
6	4.22	55	no
7	3.11	128	yes
8	2.32	35	no
9	4.92	170	yes
10	3.10	8	no

Software Toolkit

- ✓ We developed a software toolkit to **evaluate the performance of the employed LoRa communication links**, while also to collect the obtained air quality results

- ✓ The overall procedure is **orchestrated by the GW**, which periodically polls the different sensing nodes that remain in receive mode

- ✓ Sensor polling is executed in a **Round-Robin fashion**, instructing sensors to transmit collected air quality measurements (with an interval of **10 minutes**) or to participate in a **link quality evaluation experiment** (executed twice per day).

- ✓ The two procedures are executed independently of each other, taking advantage of the employed polling approach, which enables us to avoid the impact of overlapping transmission interference, when performing link quality experiments.

Link Quality Evaluation

- ✓ We developed a mechanism where the GW sends a request packet to specific sensor nodes and then the node transmits **10 consecutive packets**
- ✓ The request packet by the GW determines the:
  - ✓ **data rate,**
  - ✓ **payload length,**
  - ✓ **transmission power**
- ✓ The node replies with an acknowledgement packet in order to start the procedure
- ✓ The basic communication is realized in the **basic data rate**, while after that both transmitter and receiver are **tuned to the appropriate data rate** configuration
- ✓ The per-node link quality of the network is determined through the **Packet Delivery Ratio (PDR)** of the aforementioned experiments
- ✓ Finally, the results are forwarded to the MQTT broker through the GW and then stored on a time-series database, resulting in a distributed and scalable architecture.

Experimentation Parameters

- ✓ In our experiments we vary the:
  - ✓ **Tx Power: 0, +7, +14 dBm**
  - ✓ **Payload length: 14, 24, 44, 255 Bytes**
  - ✓ **Data rate (TX_M)**
- ✓ C/R is fixed to 4/5

TX_M	BW	SF	Data Rate (kbps)	Sensitivity	Airtime (msec)
1	125	12	293	-137	1155
2	250	12	586	-135	577
3	125	10	977	-133	329
4	500	12	1172	-129	288
5	250	10	1954	-130	164
6	500	11	2149	-128	164
7	250	9	3516	-128	82
8	500	9	7032	-122	41
9	500	8	12500	-119	23
10	500	7	21875	-116	11

Employed Data Rate Combinations

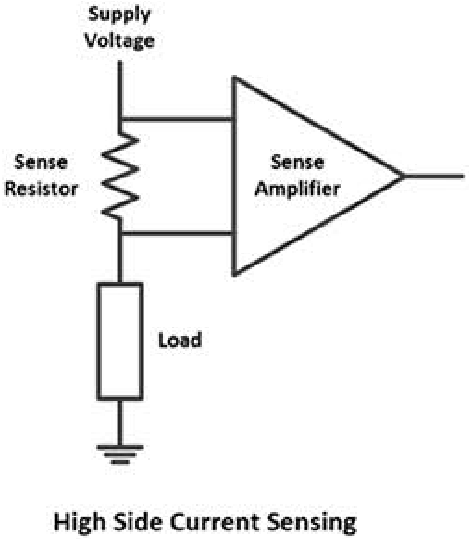
Outline

- ✓ Development and Deployment of Sensing Devices
- ✓ Software Toolkit to evaluate the performance of LoRa protocol
- ✓ LoRa Power Consumption Evaluation
- ✓ LoRa Communication Performance Evaluation

Measuring Power Consumption

- In order to measure power draw we place a shunt resistor of a known value between between the power supply and the VCC pin of the LoRa, SX1272 chipset

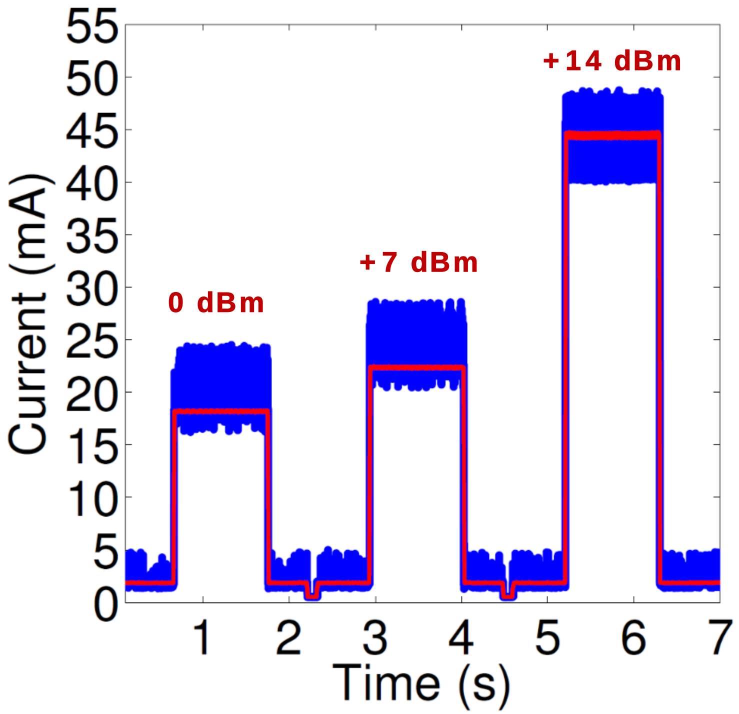
Power consumption monitoring tool



It is worth noting to note that we measure only the power draw of the SX1272 and not of the whole sensor

Varying TX_P

- ✓ In the first experiment we vary the Tx Power, from 0 to +7 and to +14 dBm, while employing the 1st TX_M to propagate data



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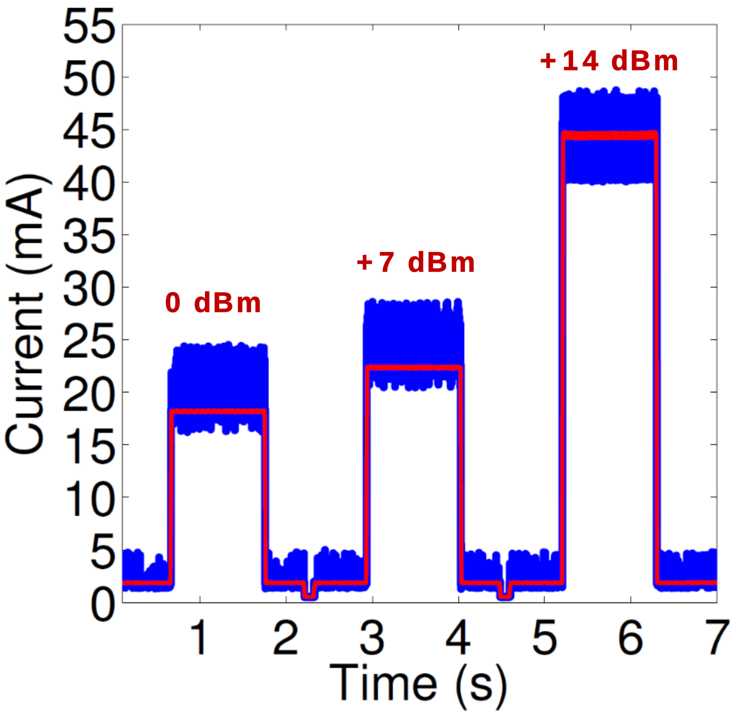


TXP	Cur. Cons.
0 dBm	18.96 mA
+7 dBm	22.13 mA
+14dBm	44.64 mA

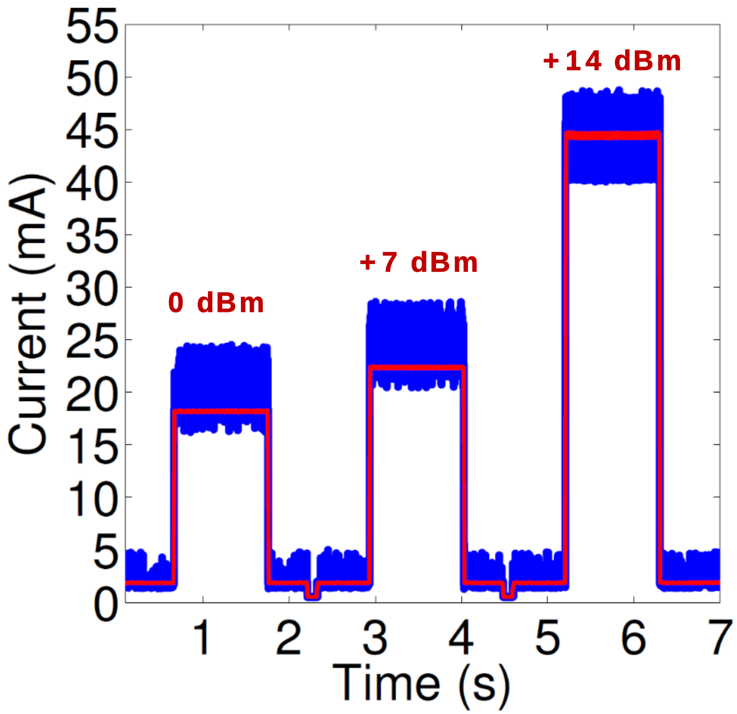
14.33 %

50.43 %

The percentage decrease of power consumption is roughly the same for the rest TXM configurations

Varying TX$_P$

✓ In the first experiment we vary the Tx Power, from 0 to +7 and to +14 dBm, while employing the 1st TX$_M$ to propagate data

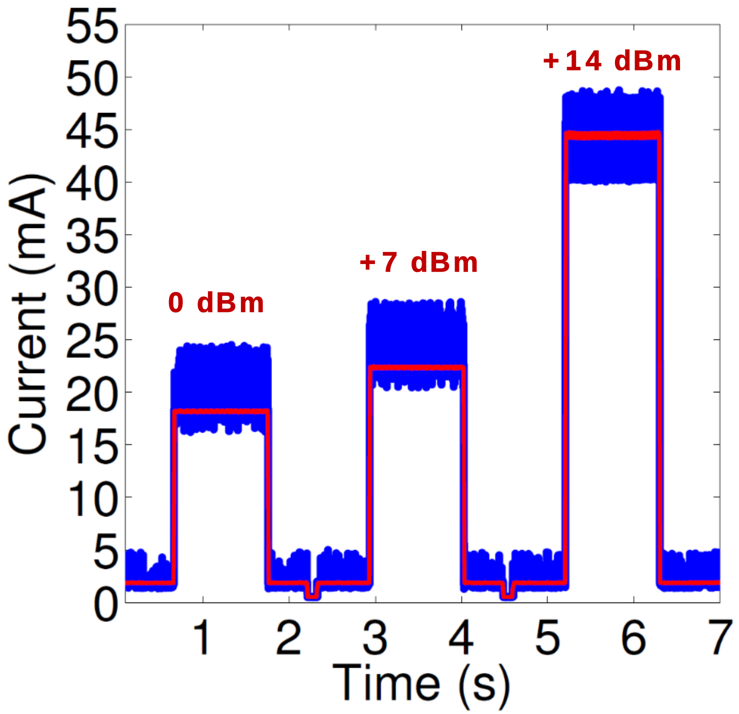


We propose skipping TX$_P$ 0 dBm and use the TX$_P$ +7 dBm to achieve higher PDR at almost the same current consumption cost

while using +7 dBm instead of +14 dBm for energy saving reasons when sufficient PDR is also attained in the case of +7 dBm

Varying TX_P

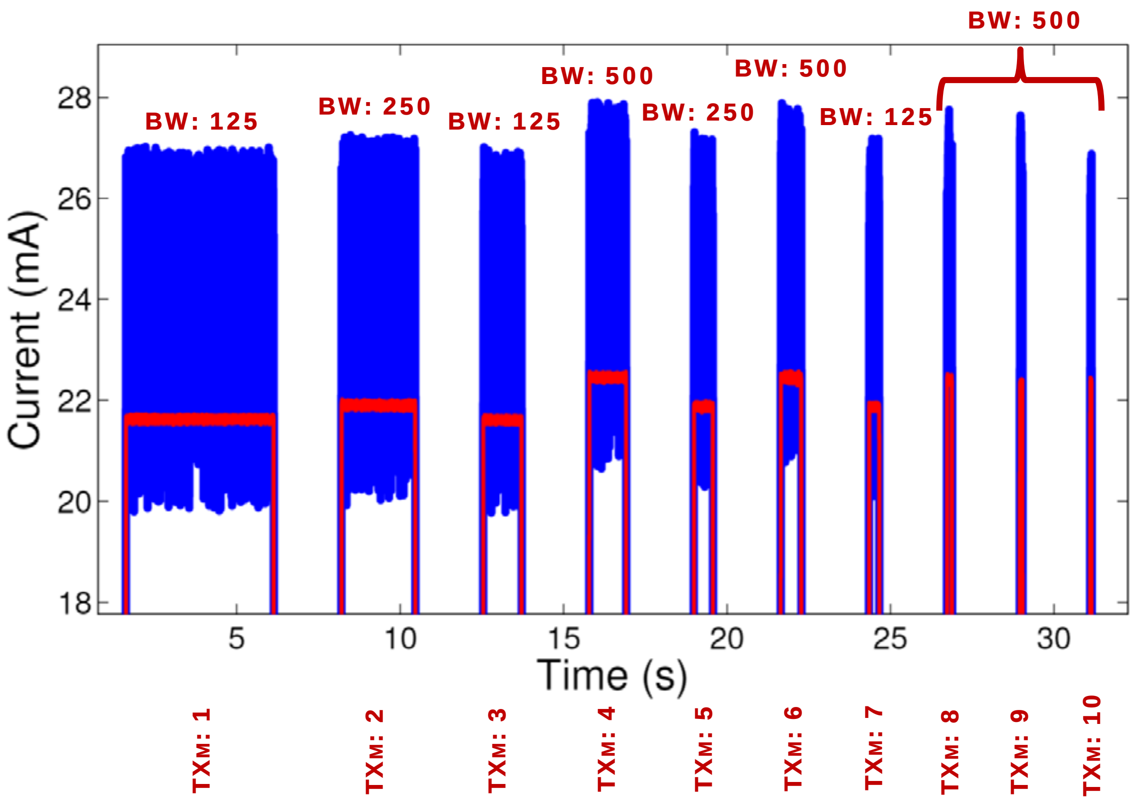
✓ In the first experiment we vary the Tx Power, from 0 to +7 and to +14 dBm, while employing the 1st TX_M to propagate data



The differentiation stems from the fact that a **Power Amplifier** circuit is engaged to amplify the signal which actually drains the most of the power when in use

Varying TX_M

- ✓ In the next experiment we set the Tx Power to +14 dBm and vary the TX_M to all available data rate configurations, for a fixed payload size (10 Bytes)



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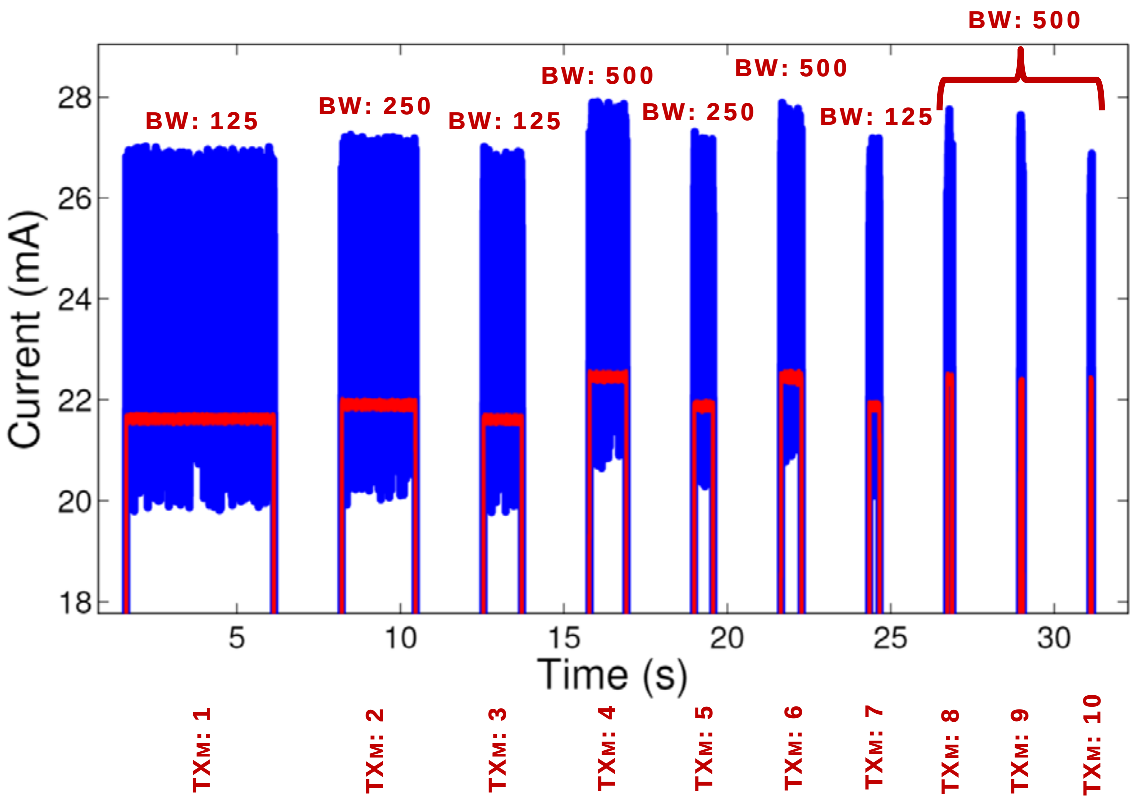
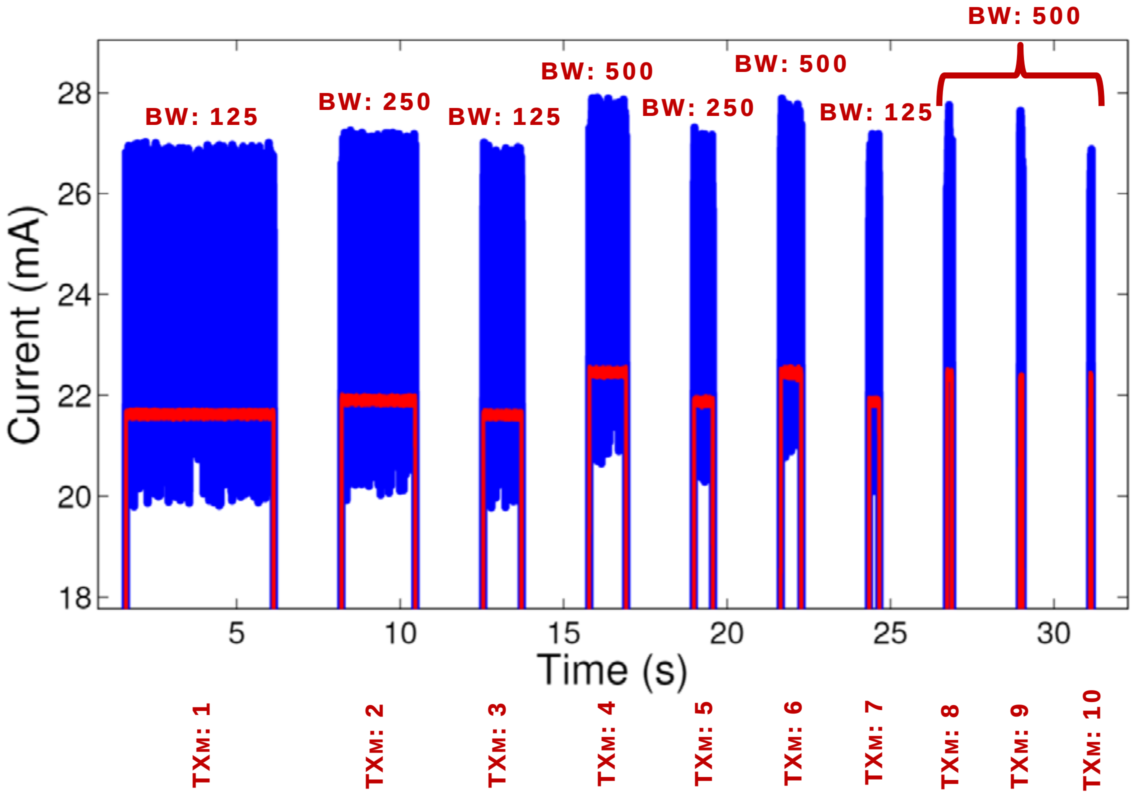


We observe that **BW** parameter plays significant role in the resulted power draw

Varying TXM

✓ In the next experiment we set the Tx Power to +14 dBm and vary the TXM to all available data rate configurations, for a fixed payload size (10 Bytes)

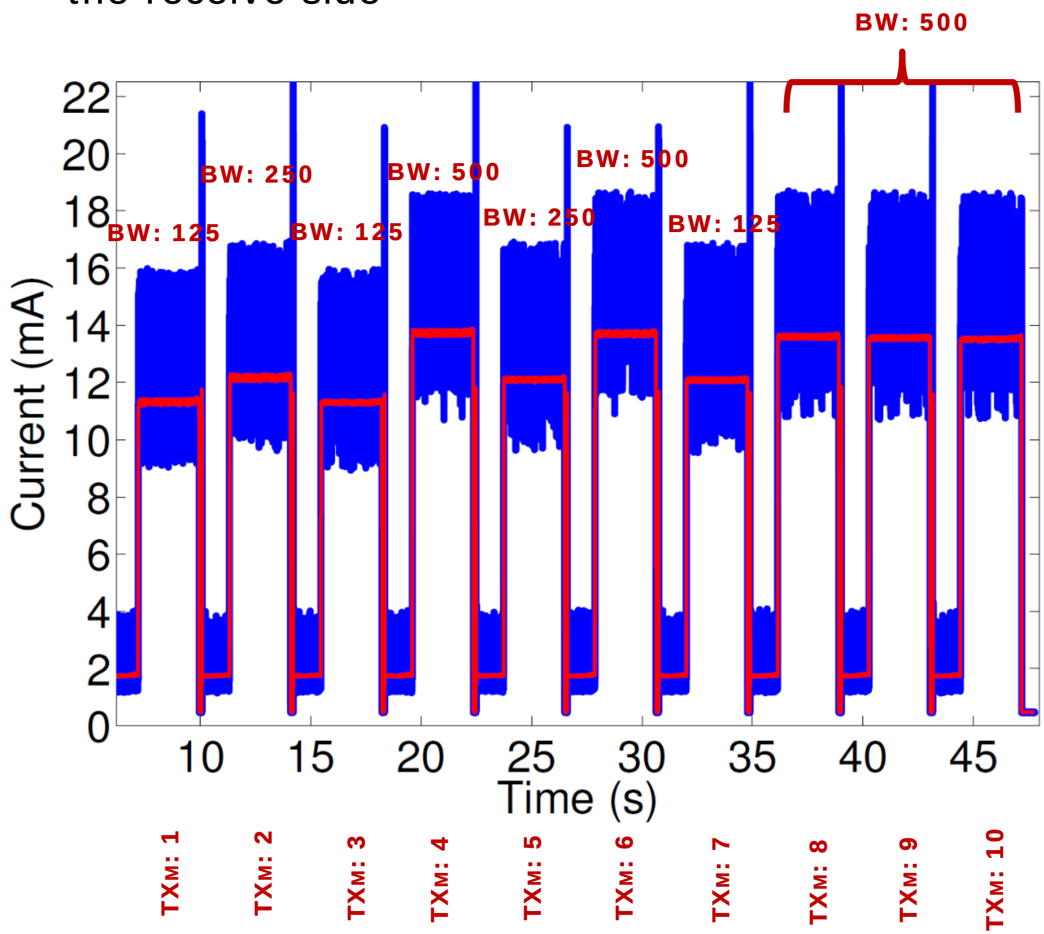


When comparing power draw under the same TXP we observe a maximum variation of **4.5 %**

(BW: 500 w/ 125 kHz)

Varying TX$_M$ – Reception Phase

✓ We repeat the same experiment (varying TX$_M$) but this time we measure at the receive side



The fact that **BW** parameter affects the obtained power draw is even more highlighted when considering the receivers consumption

Varying TXM – Reception Phase

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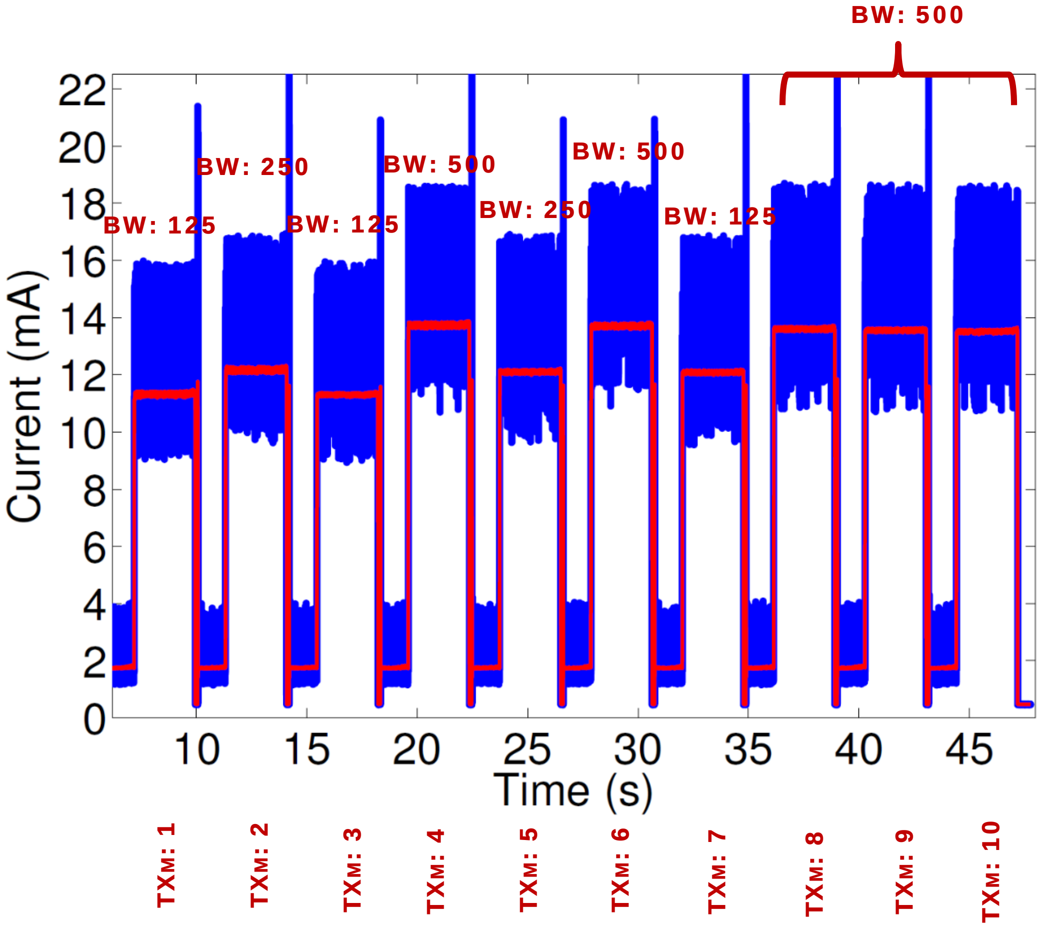


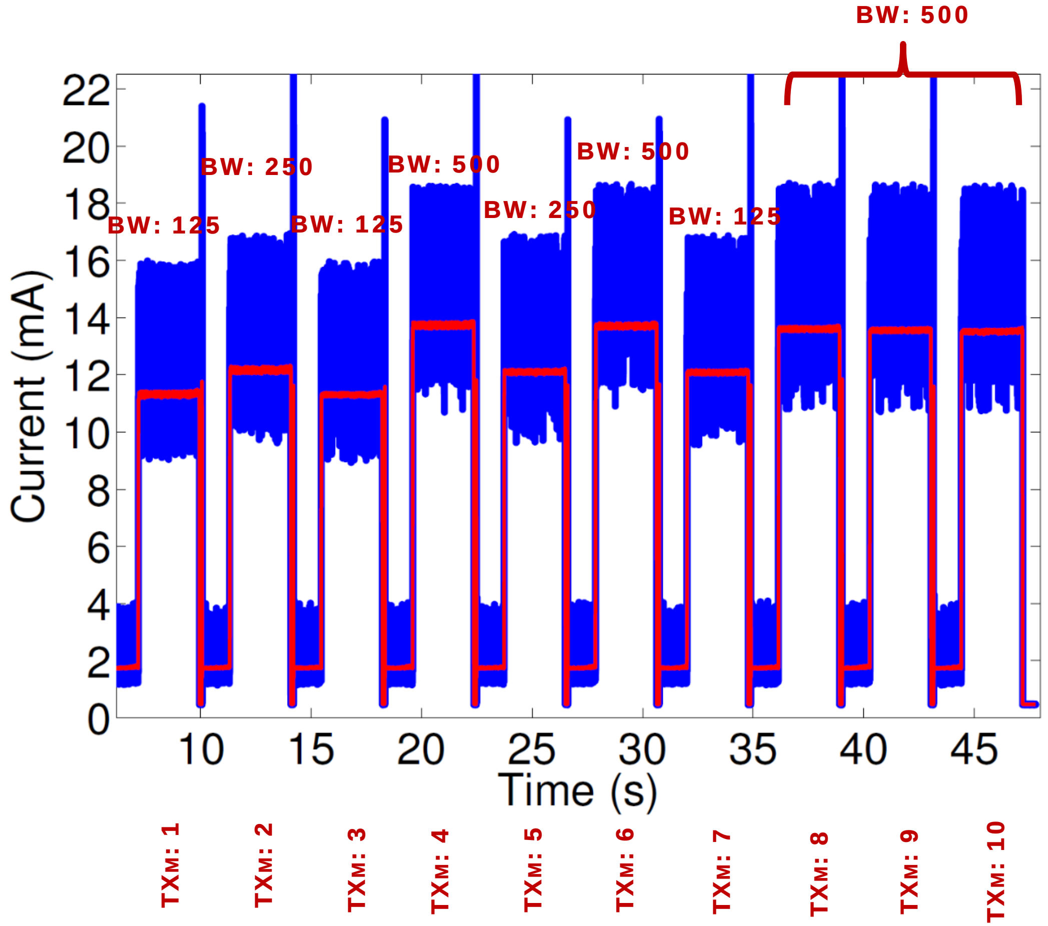
BW	Cur. Cons.
500 kHz	13.86 mA
250 kHz	12.26 mA
125 kHz	11.24 mA

11.5 %

When switching from 500 kHz to 250 kHz we obtain a reduction of 11.5 %

Varying TXM – Reception Phase

- We repeat the same experiment (varying TXM) but this time we measure at the receive side



BW	Cur. Cons.
500 KHz	13.86 mA
250 KHz	12.26 mA
125 KHz	11.24 mA

19 %

While, when switching from 500 kHz to 125kHz we obtain a substantial reduction of 19 %

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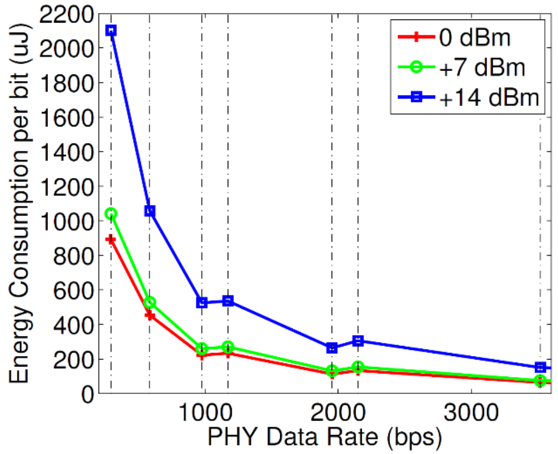
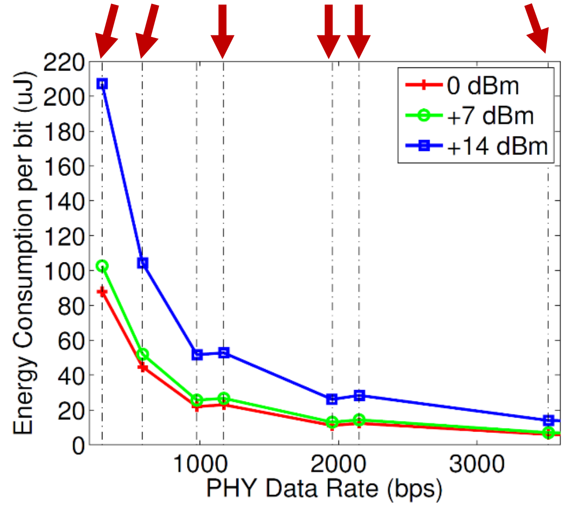
Energy Efficiency per bit in Tx

- ✓ Frame transmission duration is monotonically related to the configured data rate, thus it is important to quantify the energy efficiency, in terms of energy consumption per transmitted bit of information (E_B)
- ✓ We calculate E_B express in Joules/bit, as the division of the power consumption value by the exact data rate value

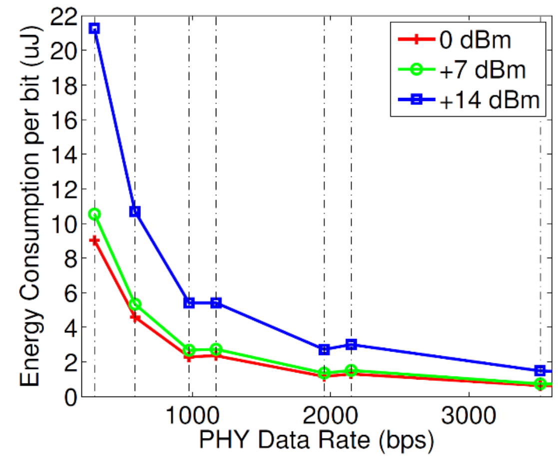
Dashed lines represent the achievable data rate of each TX_M



14 Bytes Payload



44 Bytes Payload



255 Bytes Payload

Energy Efficiency per bit in Tx

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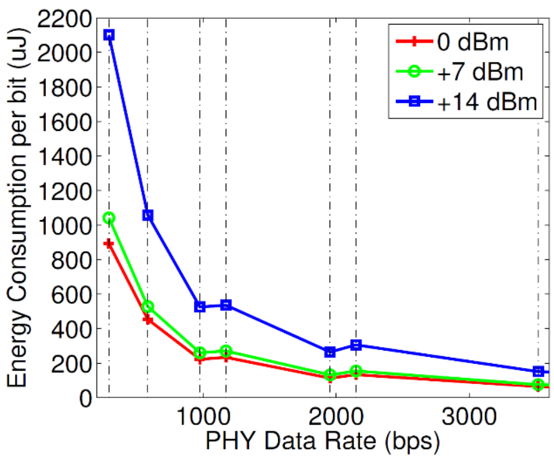
- ✓ We calculate E_B express in Joules/bit, as the division of the power consumption value by the exact data rate value

We observe identical pattern for all different Payload sizes



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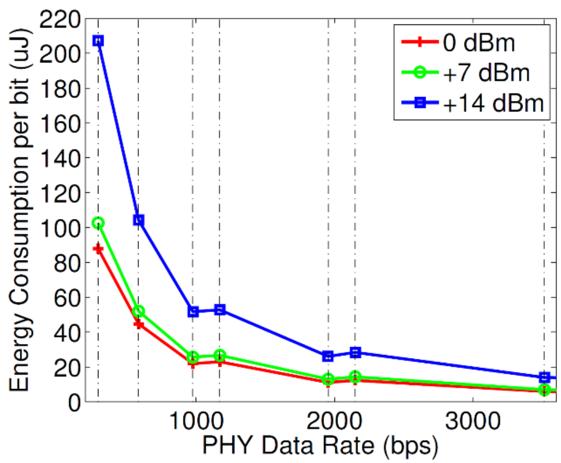

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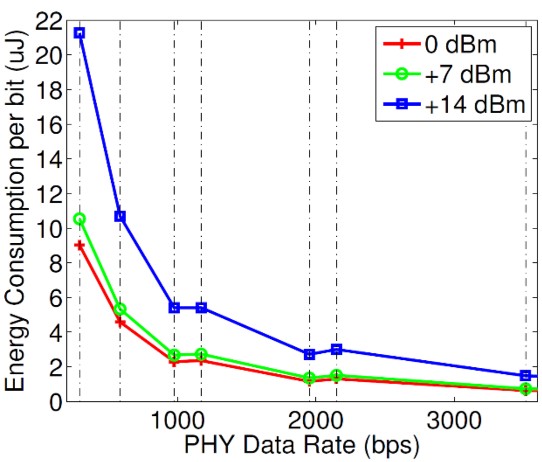

255 Bytes Payload

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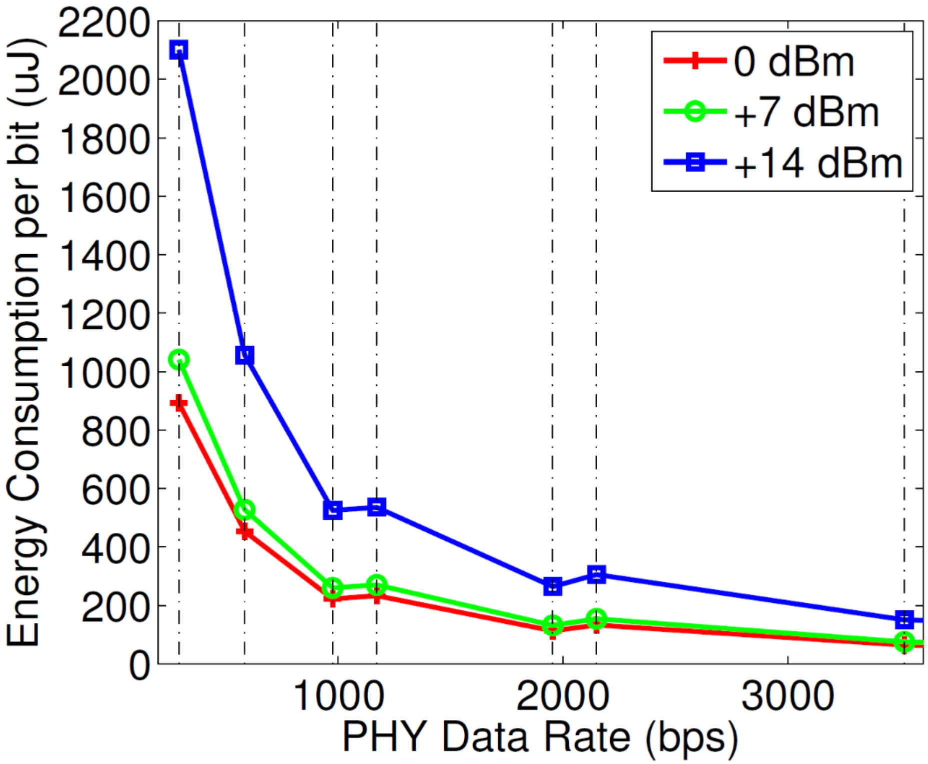
Energy Efficiency per bit in Tx

✓ Characterizing the energy efficiency in the case of 14 Bytes Payload



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Energy Efficiency per bit in Tx

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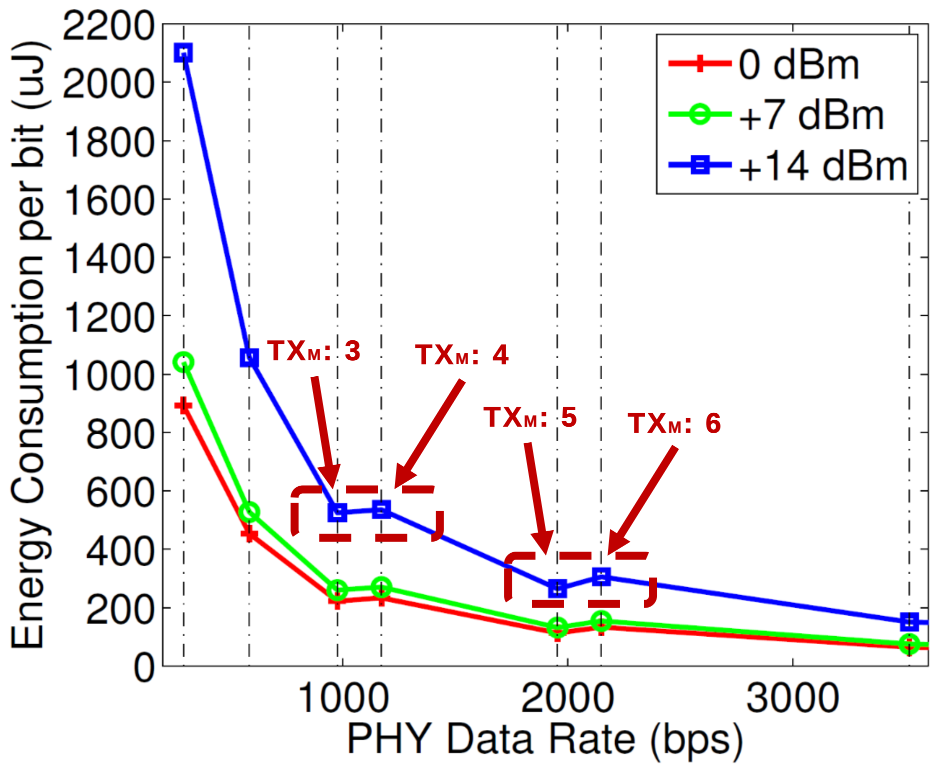
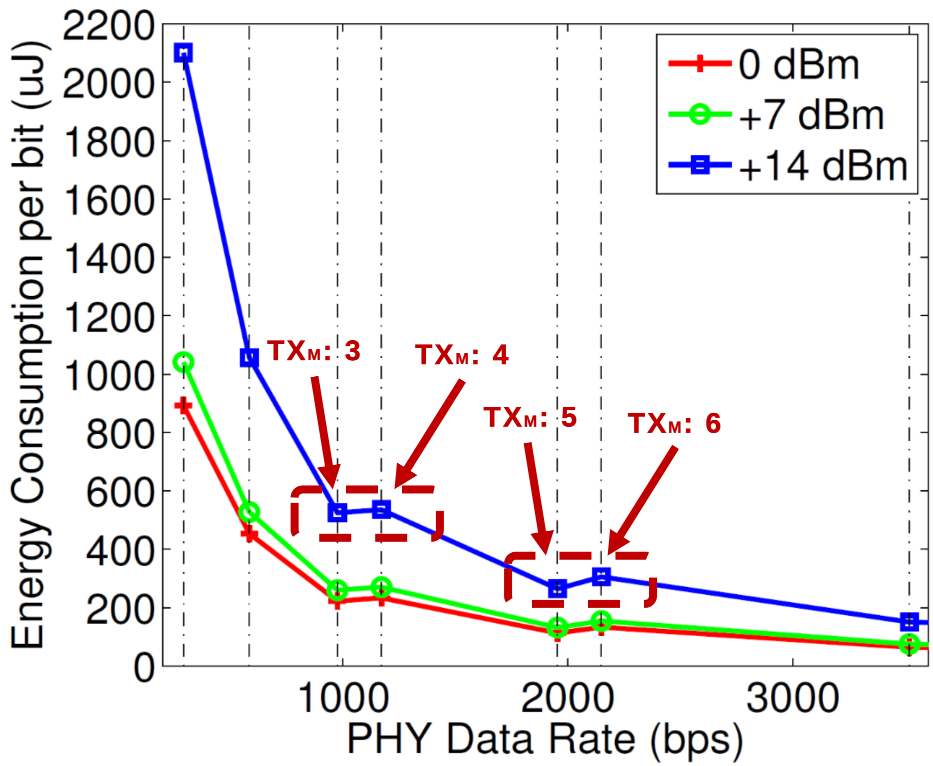


14 Bytes Payload

TXM	Current Cons.	Rate (bps)
3	44.64 mA	977
4	45.51 mA	1172
5	44.97 mA	1954
6	45.54 mA	2149

Energy Efficiency per bit in Tx

✓ Characterizing the energy efficiency in the case of 14 Bytes Payload



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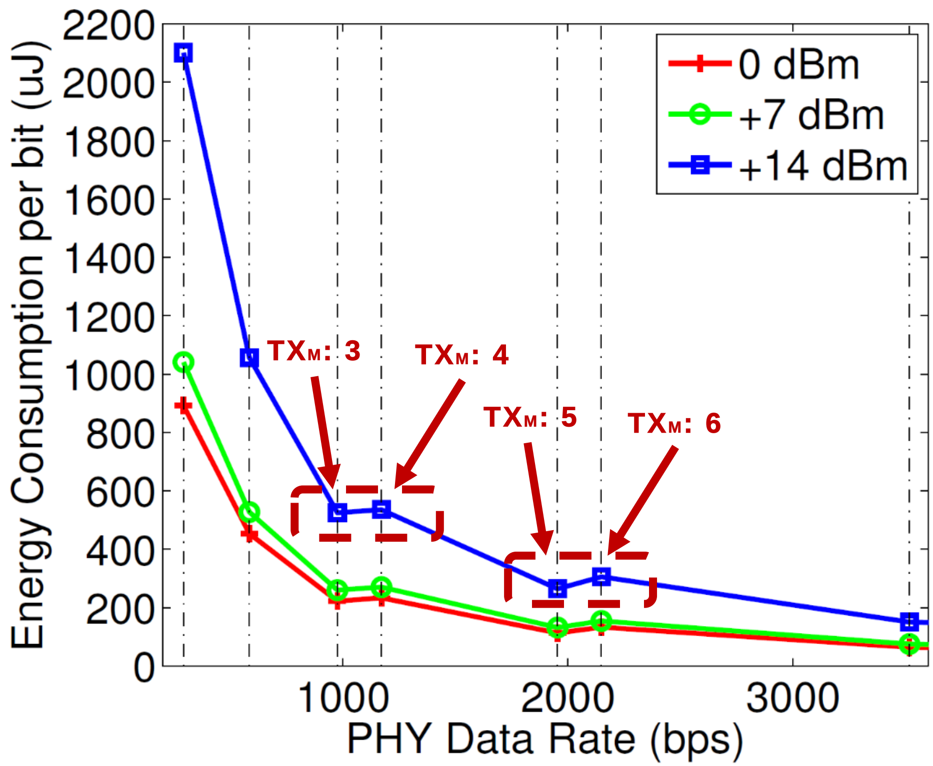

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TX_M	Current Cons.	Rate (bps)
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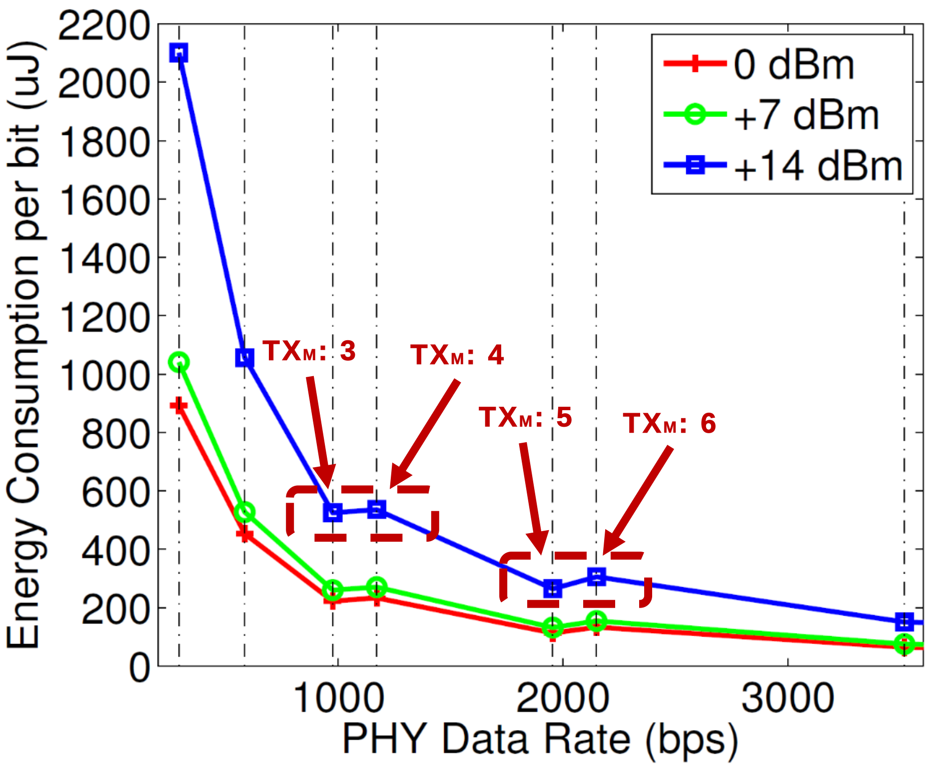
Variation of 15% between TX_M 5 and 6

Energy Efficiency per bit in Tx

✓ Characterizing the energy efficiency in the case of 14 Bytes Payload



14 Bytes Payload

We suggest skipping TXM 4 and 6

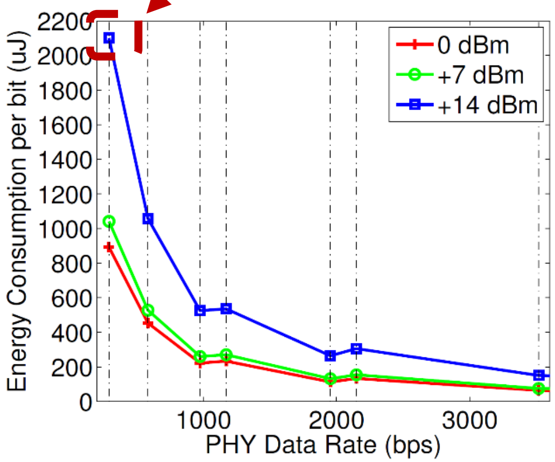
and selecting TXM 3 and 5 instead

when considering energy efficient rate adaptation algorithms

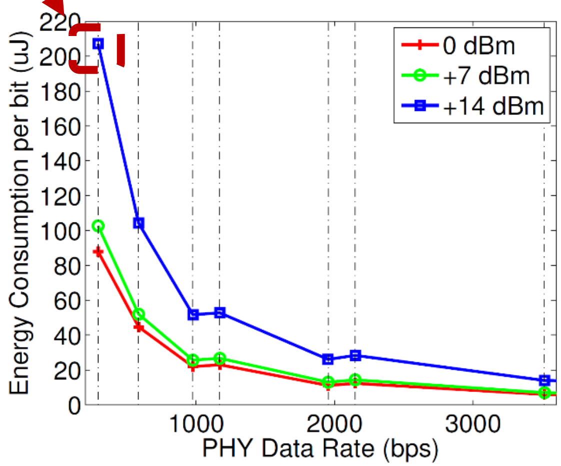
Energy Efficiency per bit in Tx

- Comparing E_B among different Payload sizes

We observe a **90%** reduction in power consumption when comparing the E_B of 14 and 44 Bytes Payload



14 Bytes Payload



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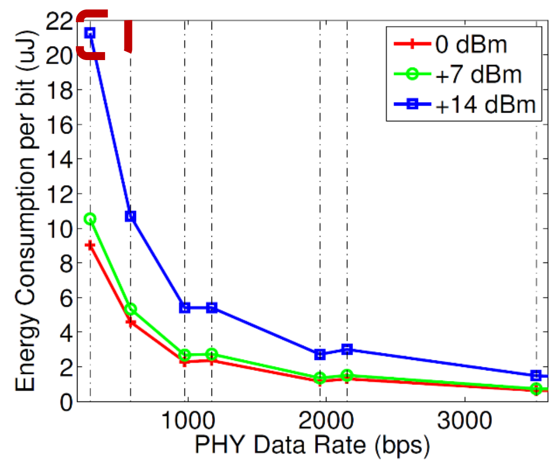
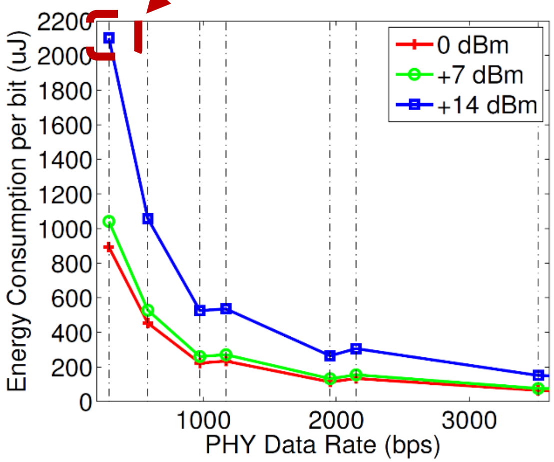


255 Bytes Payload

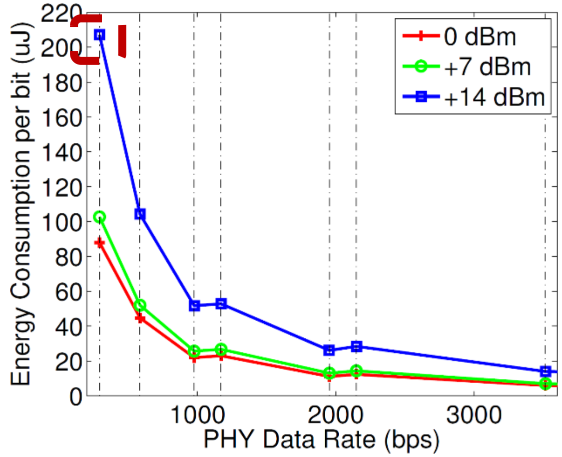
Energy Efficiency per bit in Tx

- ✓ Comparing E_B among different Payload sizes

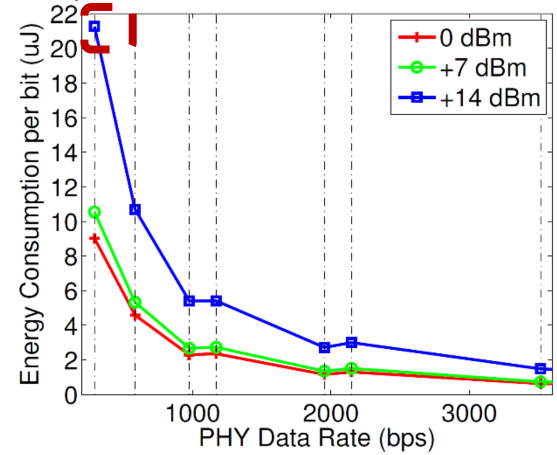
While roughly **99%** reduction is obtained when comparing the E_B of 14 and 255 Bytes Payload



14 Bytes Payload



44 Bytes Payload

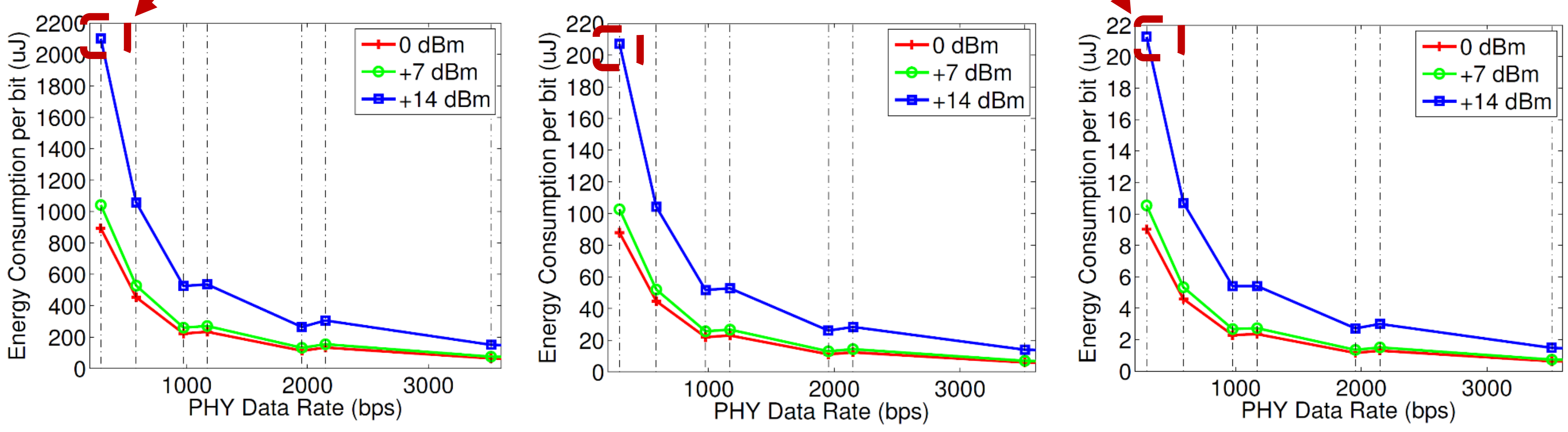


255 Bytes Payload

Energy Efficiency per bit in Tx

- ✓ Comparing E_B among different Payload sizes

While roughly **99%** reduction is obtained when comparing the E_B of 14 and 255 Bytes Payload

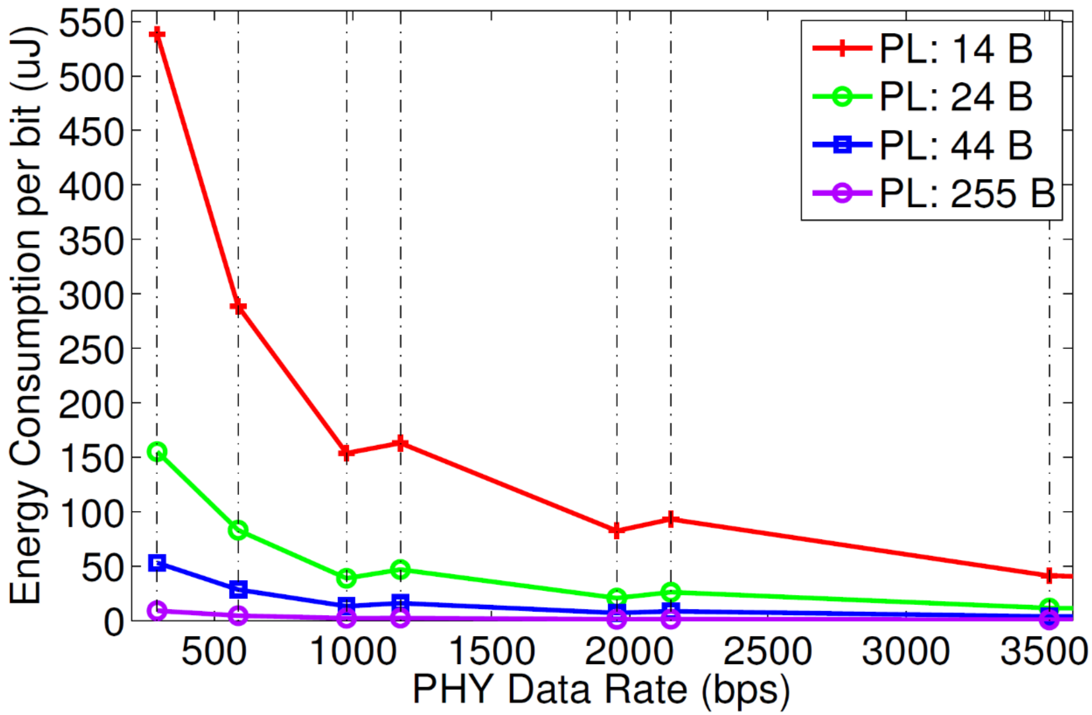


14 Bytes Payload | 44 Bytes Payload | 255 Bytes Payload

Aggregation mechanisms would substantially aid in energy savings

Energy Efficiency per bit – Receiver Side

- ✓ We calculate again the E_B, but in receiver side this time



Energy Efficiency per bit in Rx mode, across different Payloads

Energy Efficiency per bit – Receiver Side

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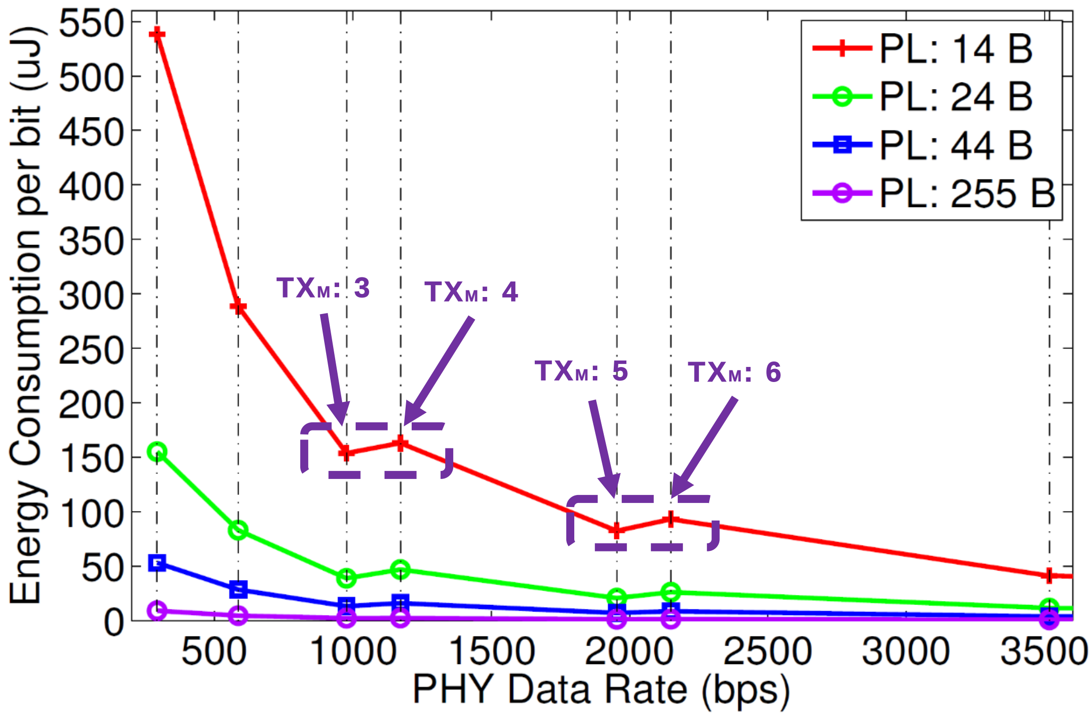

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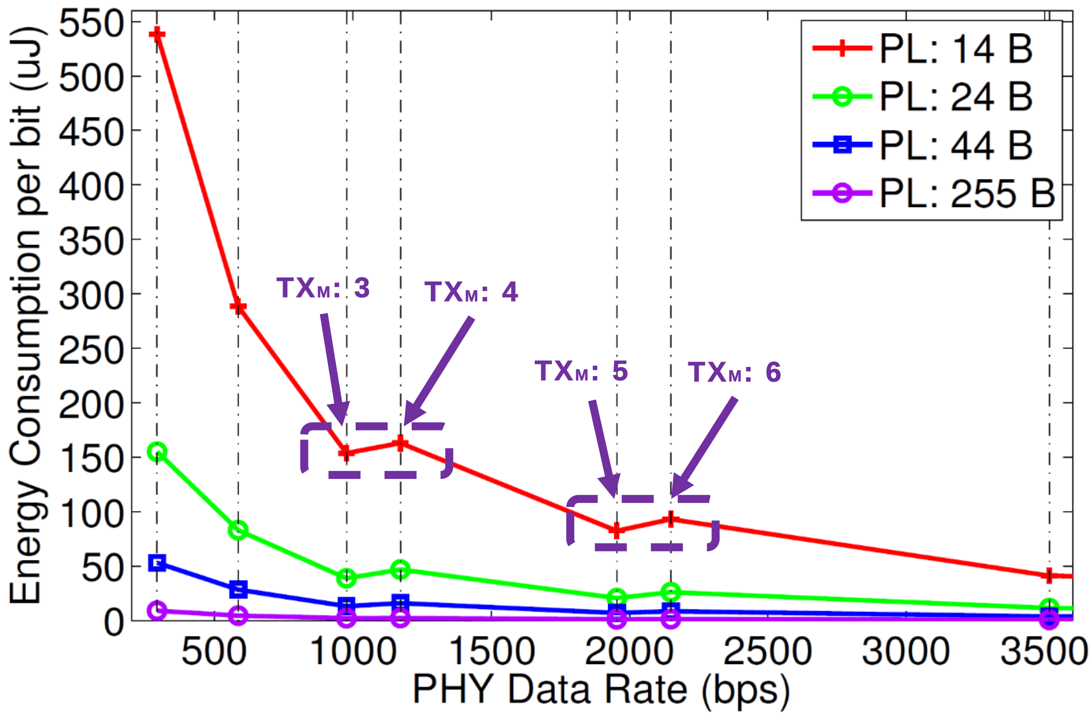

TX_M	Current Cons.	Rate (bps)
3	11.24 mA	977
4	13.86 mA	1172
5	12.26 mA	1954
6	13.86 mA	2149

Percentage decrease of 19%

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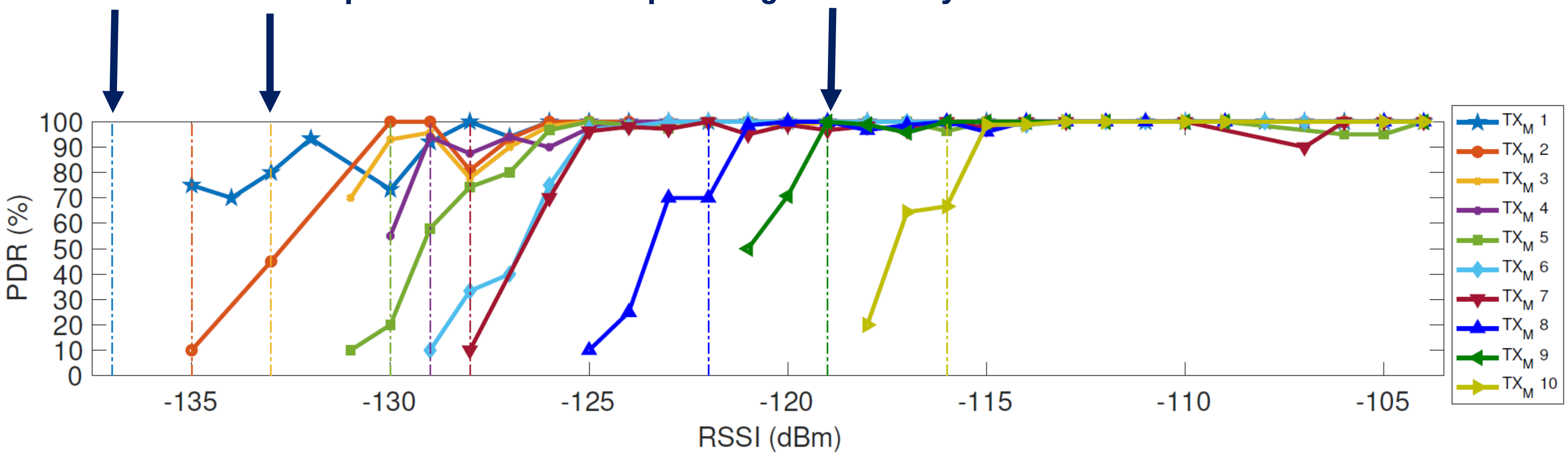
LoRa PDR Performance vs RSSI

- ✓ We plot the obtained PDR performance versus the recorded RSSI value
- ✓ Considering that we deployed 10 nodes and employ 3 different TX_P configurations, we result in 30 different link combinations

Dashed lines represent the corresponding sensitivity threshold for each TX_M

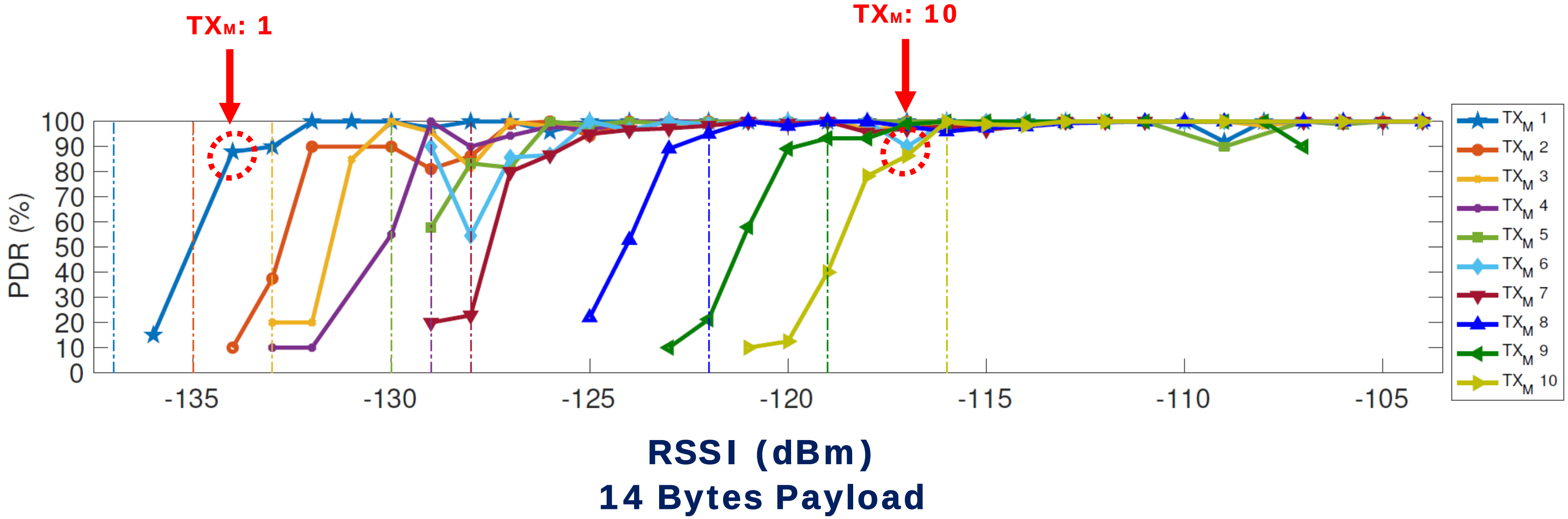


255 Bytes Payload

Solid lines represent the achievable DPR under the specific RSSI value

LoRa PDR Performance vs RSSI

- ✓ Through the plotted graphs we can characterize LoRa links performance under different conditions
- ✓ We remark that LoRa achieves **90% PDR** at **-134 dBm** when using the TX_M: 1, and at **-118 dBm** when employing TX_M: 10



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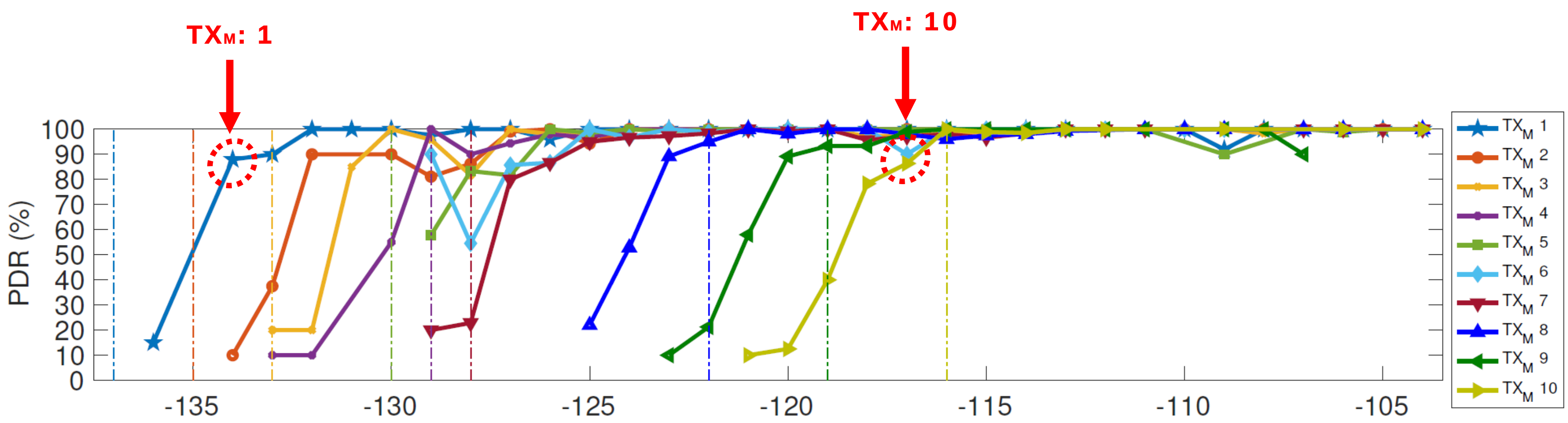
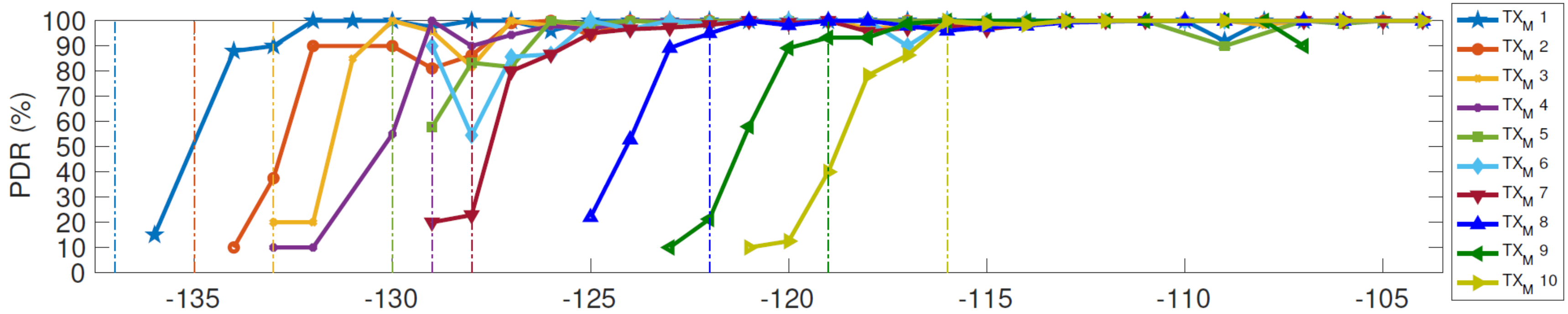
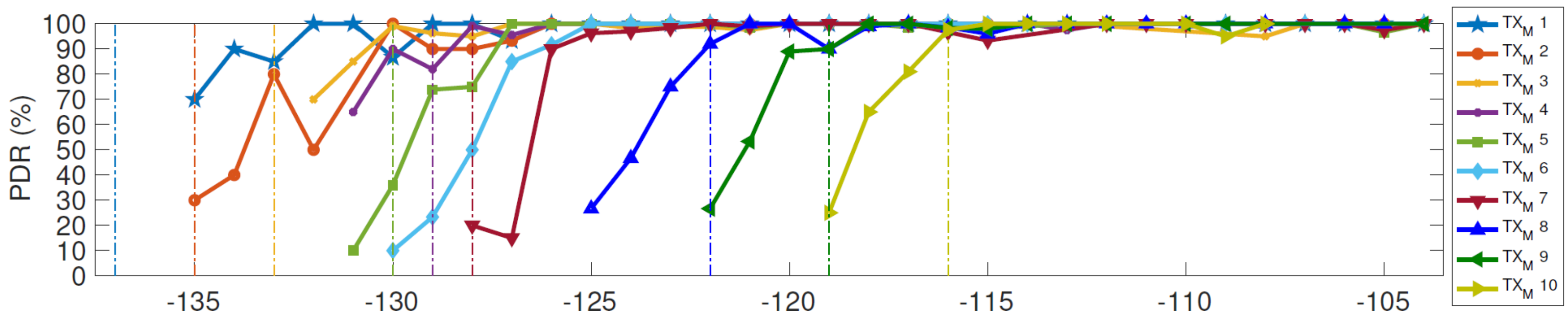


RSSI (dBm)
14 Bytes Payload

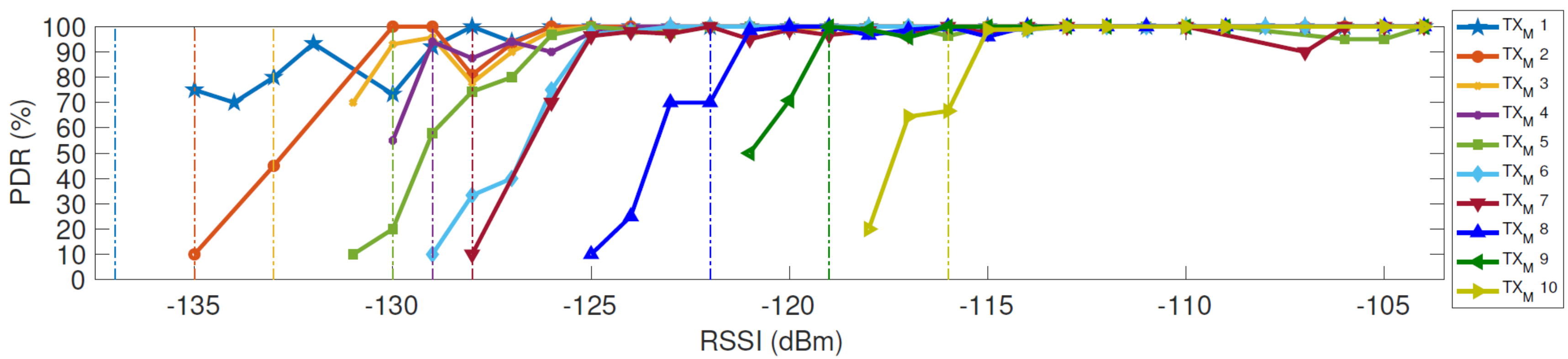
TXM 10 supports roughly 21 kbps data rate which means it can even support the transmission of low-quality video at this low sensitivity



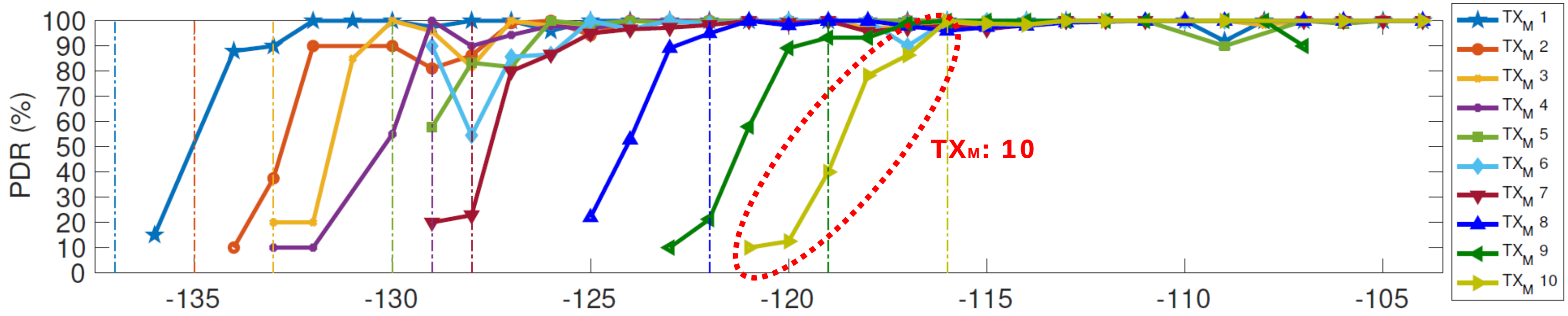
14 Bytes Payload



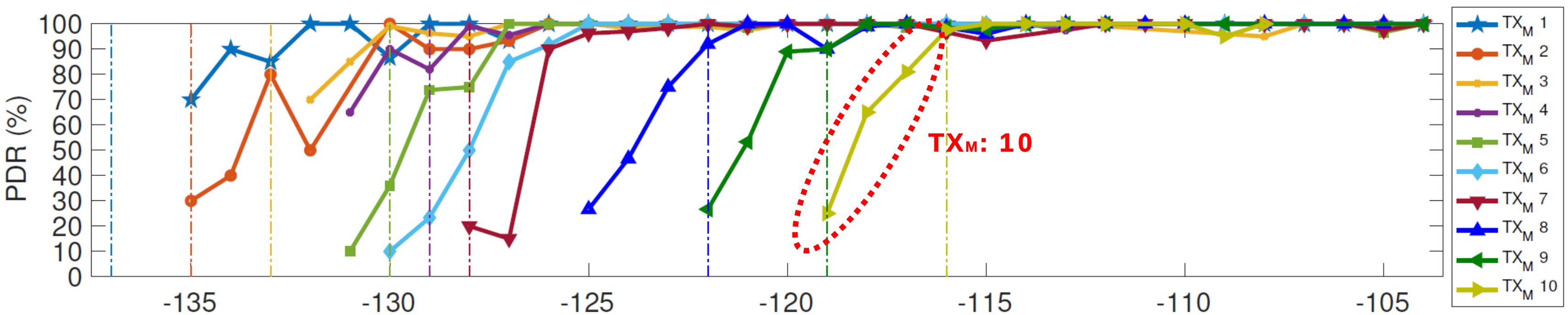
44 Bytes Payload



255 Bytes Payload



14 Bytes Payload



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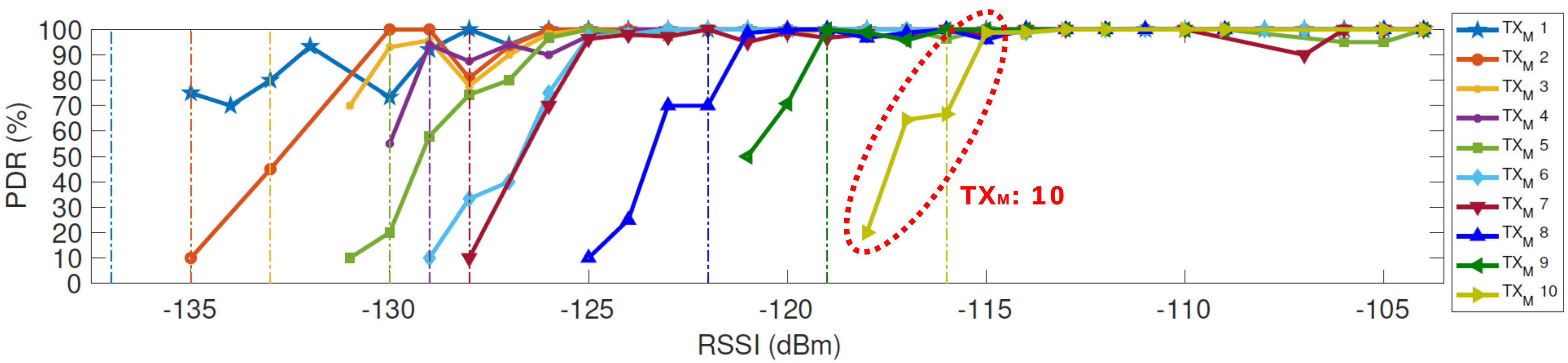
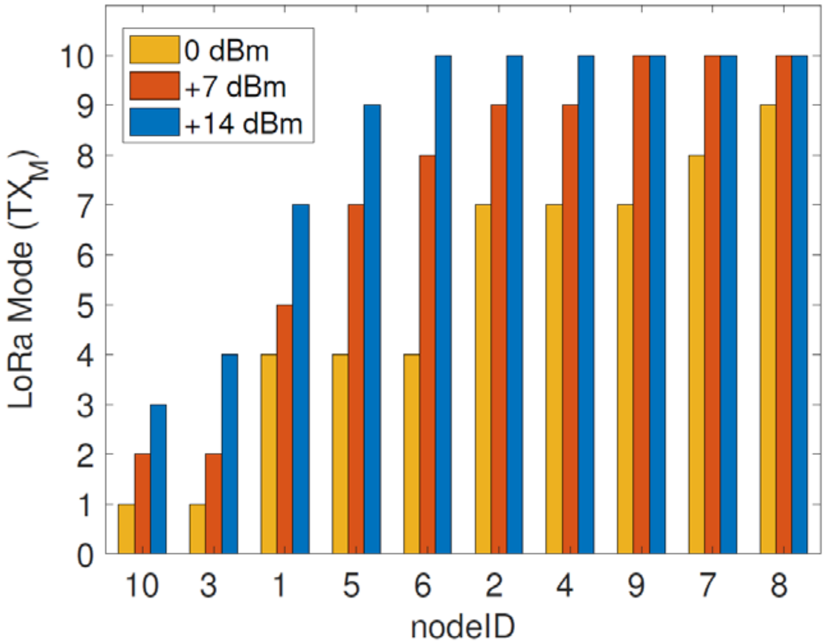


255 Bytes Payload

LoRa PDR Performance vs RSSI

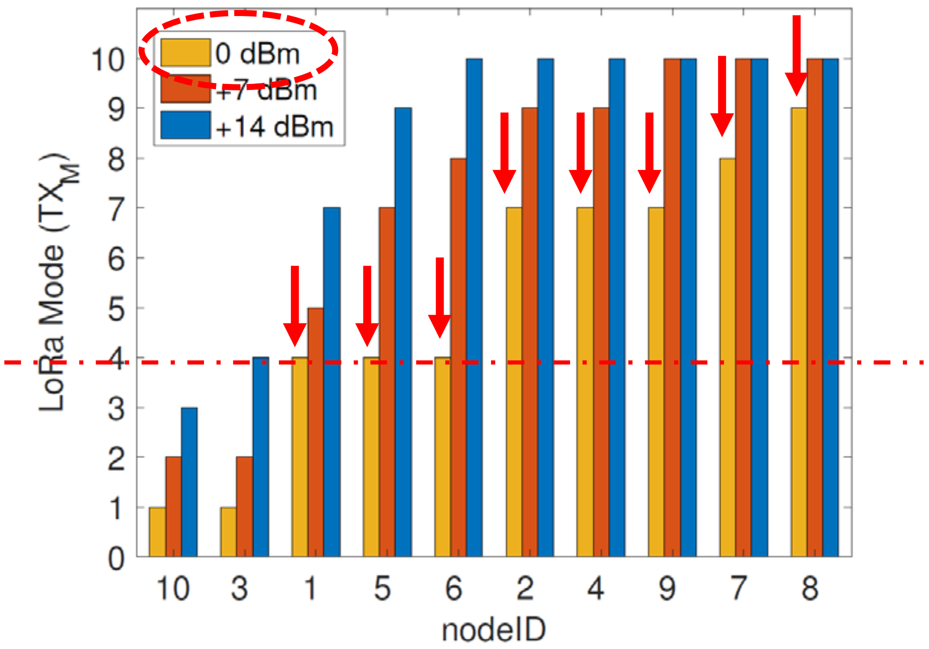
- ✓ We calculate the optimal TX_M to be used for every of the 30 resulted links of the experiment (10 nodes – 3 TX_P levels)
- ✓ We record the **maximum TX_M setting that achieves more than 90% PDR**



Maximum LoRa TX_M that provides at least 90% PDR

LoRa PDR Performance vs RSSI

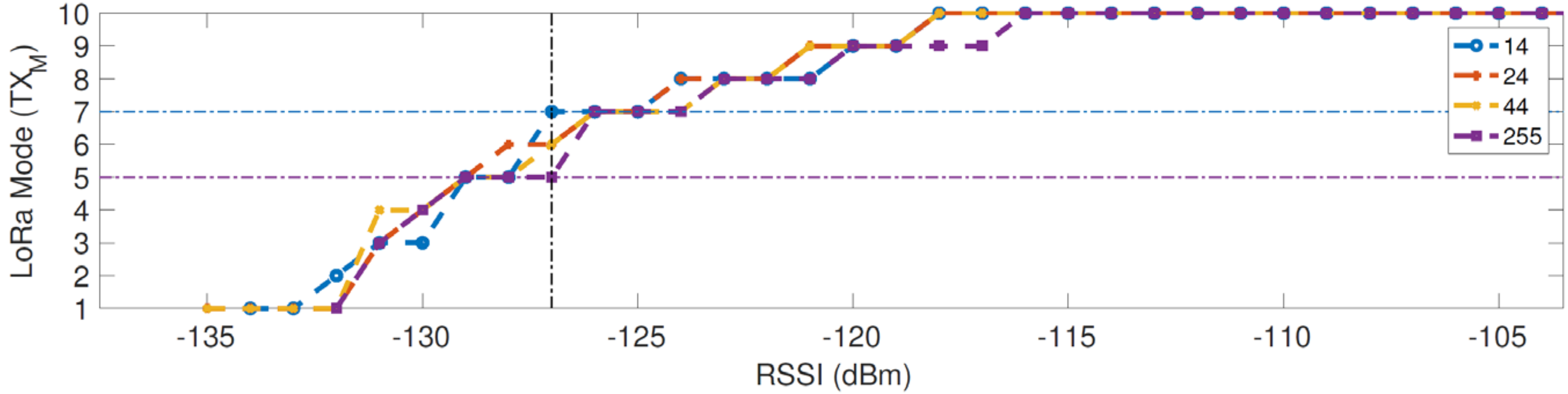
- ✓ We observe that even when using 0 dBm TX_P, LoRa can achieve 90% PDR for TX_M higher than 4 (almost in most of the cases)



Maximum LoRa TX_M that provides at least 90% PDR

LoRa PDR Performance vs RSSI

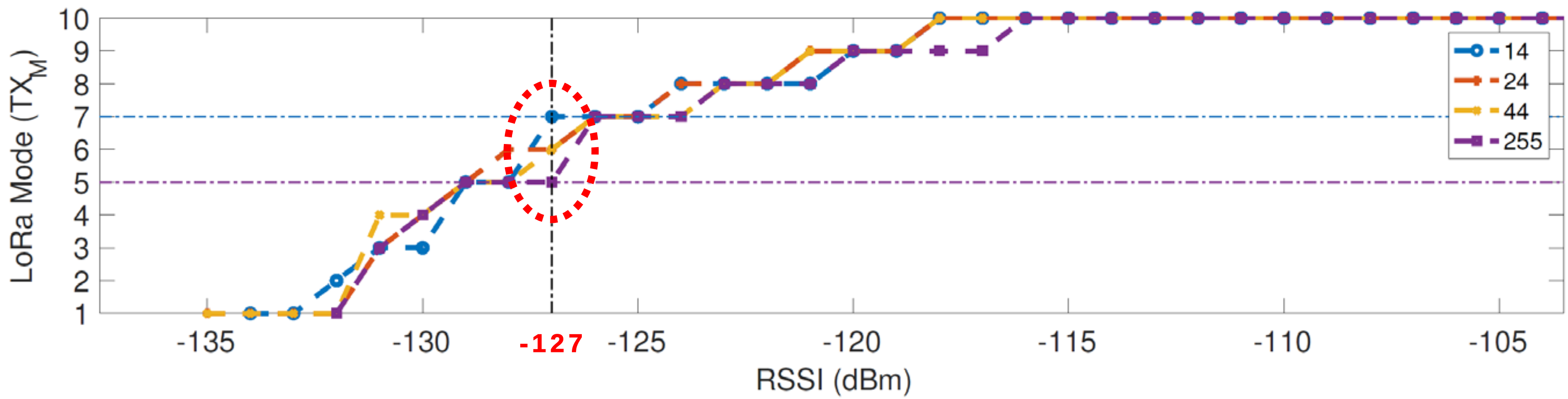
- ✓ Lastly, we map the calculated TXM that offers 90% PDR for each RSSI value under varying Payload sizes



Maximum LoRa TXM per link that provides at least 90% PDR under varying Payload

LoRa PDR Performance vs RSSI

- Lastly, we map the calculated TX_M that offers 90% PDR for each RSSI value under varying Payload sizes
- It is clear that the transmission of larger frames requires the decrease of TX_M by up to two levels as in the case of -127 dBm RSSI



Maximum LoRa TXM per link that provides at least 90% PDR under varying Payload

Thank You!

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