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DyLoRa：迈向能量高效的动态LoRa传输控制

止于至善

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01

LoRa背景

L o R a   B A C K G R O U N D

General Concepts

LPWAN：Low Power Wide Area Network（低功耗广域网）

LoRa (**Lo**ng **Ra**nge): LPWAN protocol

LoRa的物理参数：spreading factor、 transmission power、signal-to-noise ratio等

LoRa的表现评估：energy efficiency、transmission distance、noise resilience、packet delivery rate等

Energy Efficiency		
定义	消耗一定能量的平均传输比特数	每单位功耗的交付比特位数
单位	bit/mJ	

LoRa Sub Concepts

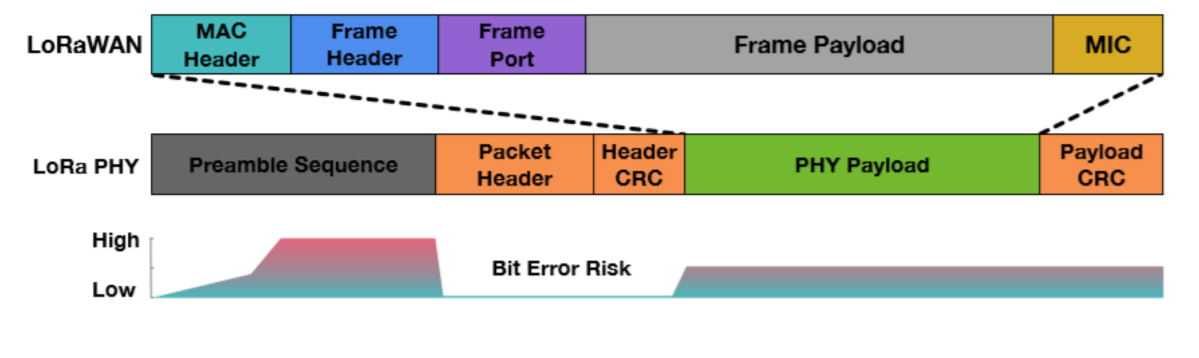
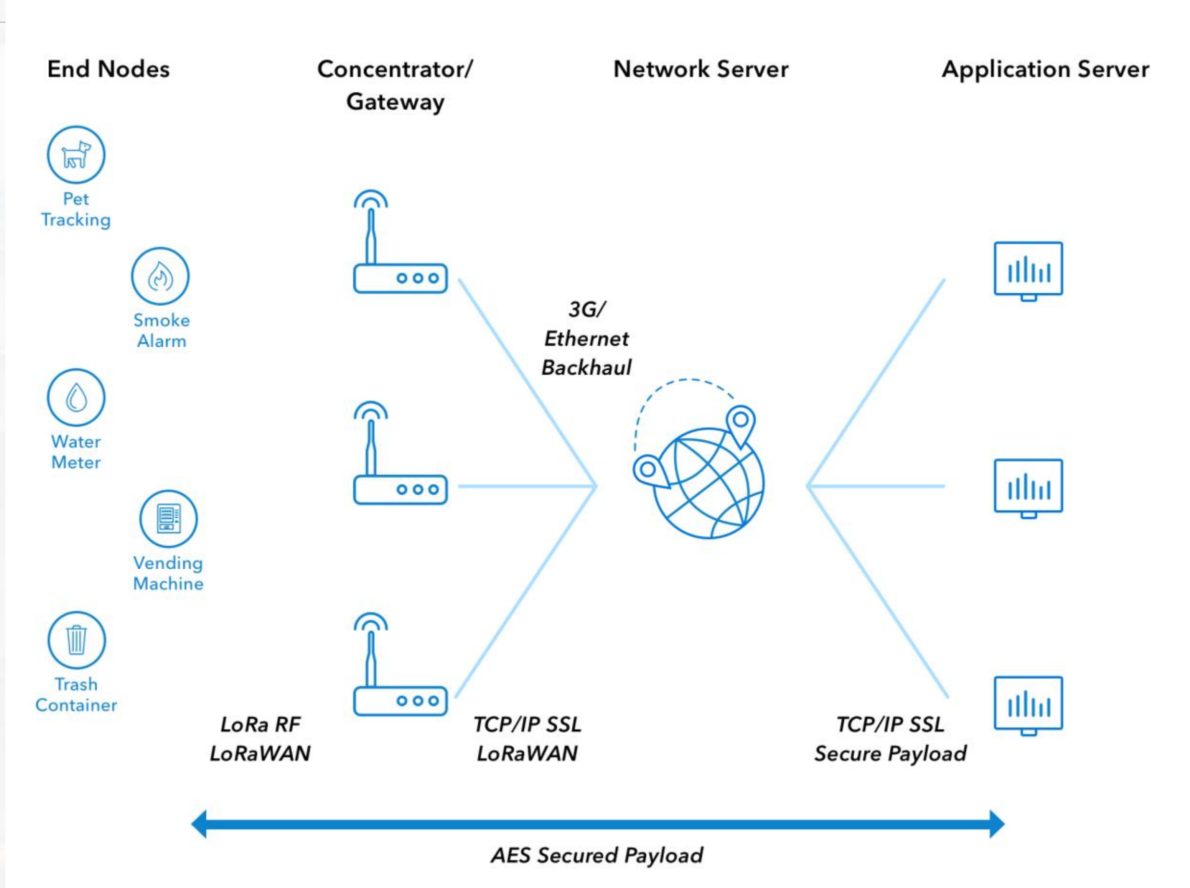


Figure 2: LoRa PHY and LoRaWAN frame components. Packet Header and Header CRC are encoded with more robust 1/2 FEC coding to protect against interference

LoRa



LoRaWAN

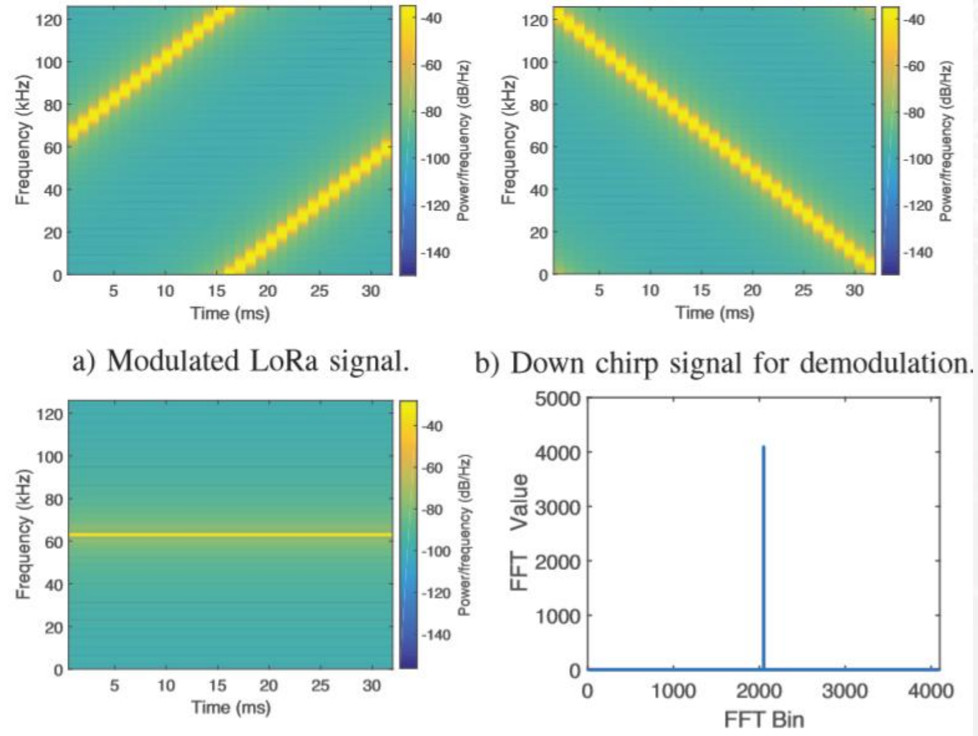
MAC protocol for WAN

LoRa Modulation/ Demodulation

Wireless Systems Frequency Modulation

①**Traditional Modulation:** Frequency Shift Keying (FSK)

②**LoRa Modulation:** Chirp Spreading Spectrum（CSS）



a) Modulated LoRa signal. b) Down chirp signal for demodulation. c) Spectrogram of LoRa signal multiplied by down chirp signal. d) Fast Fourier Transform of LoRa signal multiplied by down chirp signal.

Fig. 1: LoRa demodulation procedure. Figure a shows the spectrogram of LoRa signal. Figure b shows the spectrogram of down chirp signal. When the gateway receives a LoRa signal, it multiplies the LoRa signal with a down chirp signal. The spectrogram of the product is shown in Figure c. Then the gateway applies fast fourier transform (FFT) on the product, and chooses the frequency of the FFT peak to calculate the symbol. Figure d shows the FFT result.

Physical Parameters

Spreading Factor

Definition: a chirp is modulated with SF bits

$$T = \frac{2^{SF}}{B} \tag{1}$$

Chirp Duration ∝ 2^SF

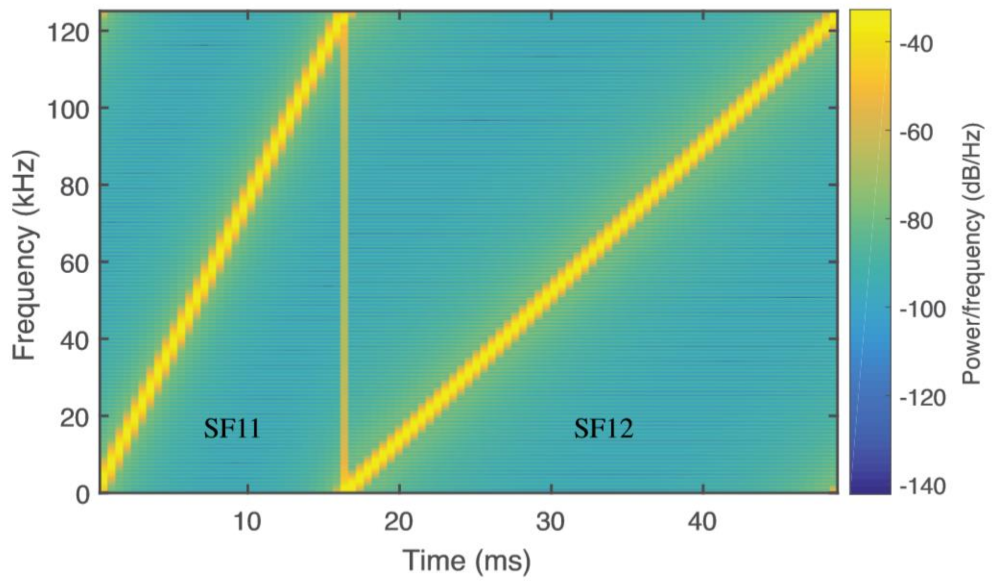


Fig. 2: The symbol durations are different under different SFs.

$$DR = \frac{SF \cdot B}{2^{SF}} \tag{2}$$

Data rate (bit/s)

SF ↑ -> Symbol duration ↑ -> FFT value ↑ -> PDR ↑

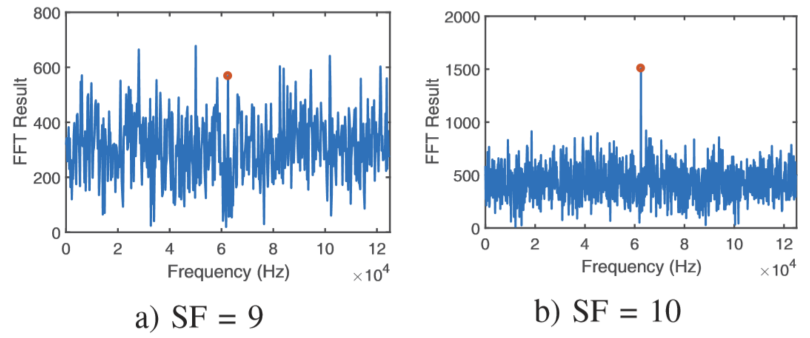


Fig. 3: The blue line indicates the Fast Fourier Transform result of all frequencies. The red circle indicates the FFT result of the target frequency. LoRa packet is more resilient to noise with larger SF under the same noise level. Figure a shows when SF=9, the FFT result of at the target frequency is not strongest, so the symbol will not be correctly decoded. Figure b shows when SF = 10, the signal's FFT result at the target frequency is the largest, and the symbol will be successfully decoded.

Transmission Power：

TP ↑ -> RSSI ↑ -> SNR ↑ -> PDR ↑

TABLE II: Transmission Power Level and Gain (signal gains)

Power Level	7	6	5	4	3	2	1	0
Power (mW)	205	230	250	276	303	350	402	439
Gain (dBm)	0	1.6	2.8	4	5.2	6.4	7.7	8.9

(表中准确数值与硬件有关，这里是用power monitor测的，且整个实验只测了一遍)

ADR (Adaptive Data Rate control)

负反馈调节： NS根据uplink，发送downlink调整device

公式： SNRmargin = SNRm – SNR(DR) – margin_db

①(SNRmargin > 0) ? (SF ↓ && TP ↓) : TP ↑

参数： ②SNRm: measured indicator of link quality

③SNR(DR): LoRa Demodulator SNR

④margin_db: theoretical default setting

SpreadingFactor (RegModulationCfg)	Spreading Factor (Chips / symbol)	LoRa Demodulator SNR
6	64	-5 dB
7	128	-7.5 dB
8	256	-10 dB
9	512	-12.5 dB
10	1024	-15 dB
11	2048	-17.5 dB
12	4096	-20 dB

结论： 选择能保证LoRa符号解调成功的最小SF (最大DR)，这样传输速度快、时间短且功耗低

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02

介绍

INTRODUCTION

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DyLoRa：动态LoRa传输控制系统，动态选择物理参数的方法

思想：根据Link Properties表征能源效率的模型，从而设置物理参数

贡献：DyLoRa比**State-of-art**方法ADR平均提高了41.2%的能量效率

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03

动机

MOTIVATION

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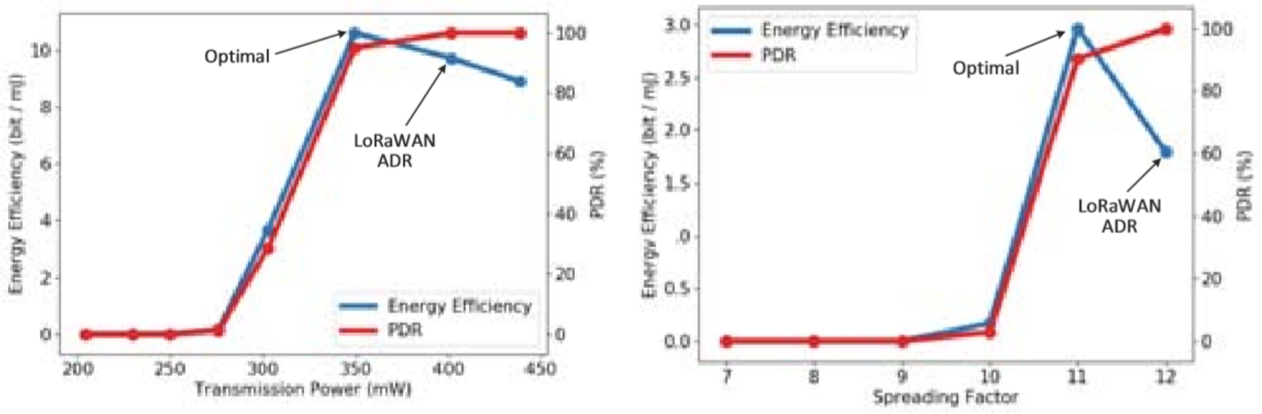
MOTIVATION

动机：证明使用ADR的能源效率仍然远远达不到实际可实现的最优能源效率

$$EE(TP, SF) = \frac{DR(SF) \times PDR(TP, SF)}{TP}$$



a) Impact of transmission power. b) Impact of spreading factor.

Fig. 4: The transmission power and spreading factor impact the packet delivery rate and energy efficiency. Figure a shows the impact of transmission power on energy efficiency and the transmission power selection results. Figure b shows the impact of spreading factor and the selection results. LoRaWAN ADR results in suboptimal energy efficiency choice.

(Empirical experiment)

结论：ADR声称尽可能小选择的SF和TP，但结果显示ADR倾向于为了PDR选择较大的SF和TP

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DyLoRa设计

DyLoRa DESIGN

设计概述

系统架构：DyLoRa = DyLoRa Gateway + DyLoRa Node

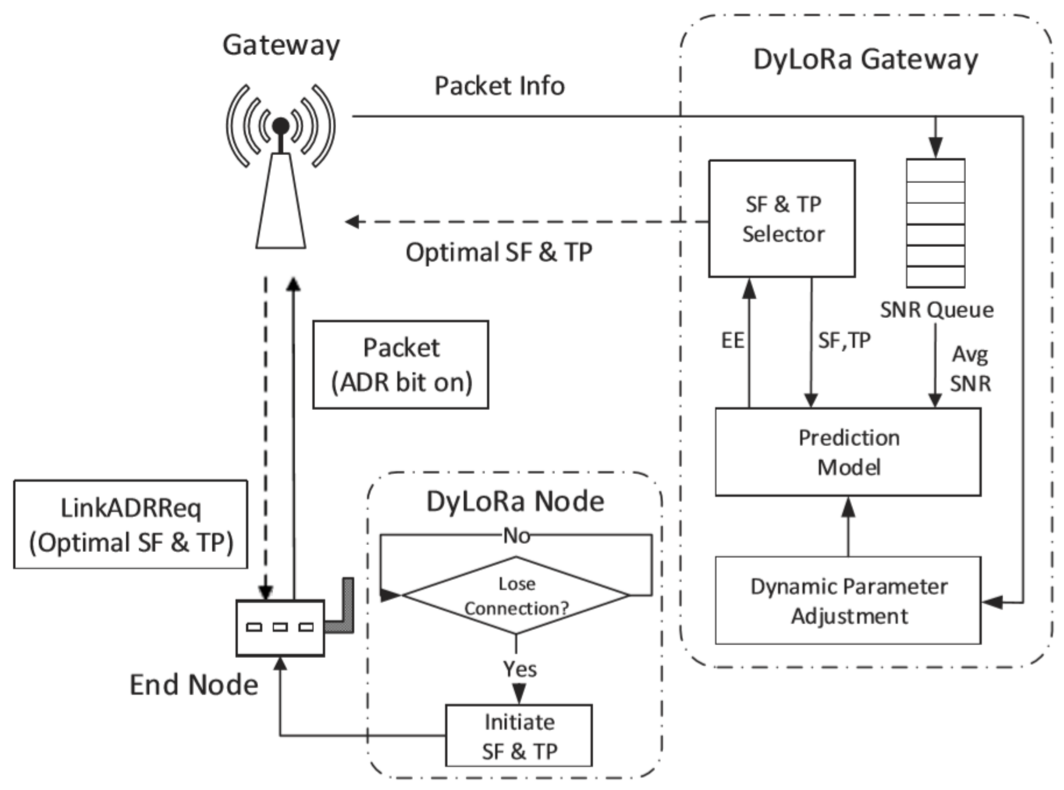

Fig. 5: System Architecture of DyLoRa

Algorithm

Algorithm 1 SF & TP Selection Algorithm

1: snr: packet snr; tp_{list}: power level 0 to 7
2: sf_{list}: sf7 to sf12; bw: bandwidth; cr: coding rate
3: n_p: preamble length; L_h: header length; L_p: payload length
4:
5: $snr_{es} = Average(snr_{stack})$
6: **for** tp,sf in tp_{list},sf_{list} **do**
7: $\quad ee = GetEE(sf, snr_{es}, cr, n_p, L_h, L_p)$
8: $\quad$ **if** ee is optimal **then**
9: $\quad\quad Return(sf, tp)$
10: $\quad$ **end if**
11: **end for**

1-3：算法输入

5：计算历史数据包的平均信噪比

6-11：循环TP和SF的6*8种组合带入GetEE算出最大EE时返回参数SF、TP

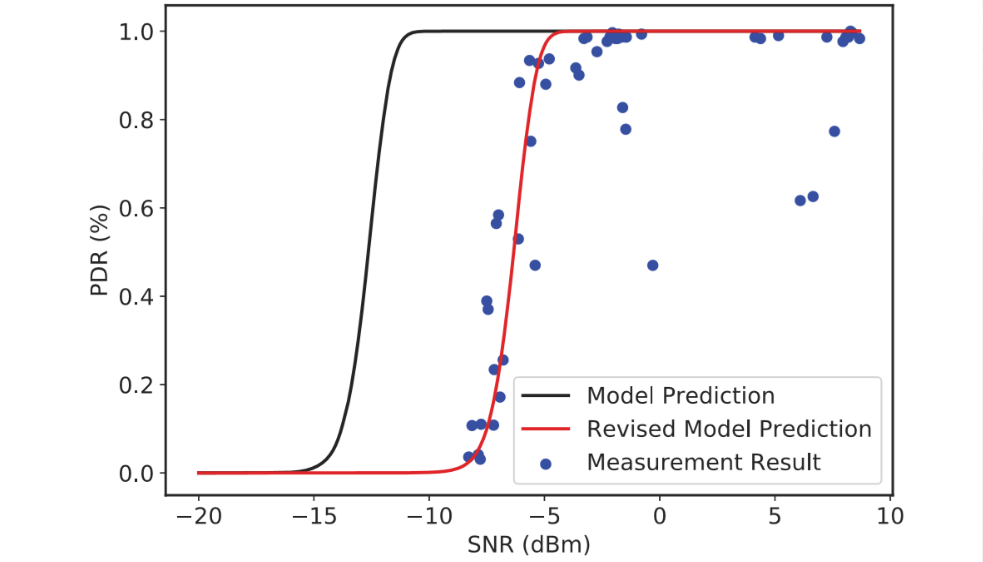

Fig. 7: PDR Gap between model predictions and measurement results. SF = 7.

SF	7	8	9	10	11	12
SNR offset (dBm)	-6.3	-6.5	-6.8	-7.3	-8	-9.5

measure data from our testbed

DyLoRa DESIGN

Model

13: **Function** $GetEE(sf, snr_{es}, cr, n_p, L_h, L_p)$
14: $br = sf \times bw/2^{sf}$
15: $snr = snr_{es} + Gain(tp)$
16: $\Gamma = 10^{(snr+offset(sf))/10}$
17: $P_b = 0.5 \times Q(\sqrt{\Gamma \times 2^{sf+1}} - \sqrt{1.386 \times sf + 1.154})$
18: $P_h = ((1-P_b)^4 + 3(1-P_b)^7 P_b)^{\lceil L_h/2SF \rceil}$
19: **if** CR equals 1 or 2 **then**
20: $\quad P_p = (1-P_b)^{\lceil L_h/SF \rceil}$
21: **else**
22: $\quad P_p = ((1-P_b)^4 + 3(1-P_b)^{3+CR} P_b)^{\lceil L_h/4SF \rceil}$
23: **end if**
24: $sf' = sf + log_2(n_p)$
25: $P_{pre} = 0.5 \times Q(\sqrt{\Gamma \times 2^{sf'+1}} - \sqrt{1.386 \times sf' + 1.154})$
26: $pdr = P_{Pre} \times P_{header} \times P_{payload}$
27: $ee = dr \times pdr/tp$
28: Return ee

Preamble	PHDR	PHDR_CRC	PHYPayload	CRC

Fig. 6: LoRa PHY Packet Format

TABLE II: Transmission Power Level and Gain

Power Level	7	6	5	4	3	2	1	0
Power (mW)	205	230	250	276	303	350	402	439
Gain (dBm)	0	1.6	2.8	4	5.2	6.4	7.7	8.9

14：
$$DR = \frac{SF \cdot B}{2^{SF}}$$

15：
$$PDR(TP, SF) = PDR(SNR' + Gain(TP', TP), SF)$$

16：
$$PDR(SNR, SF) = PDR(SNR' + Gain(TP', TP) + offset(SF), SF)$$

17：
$$P_b(SNR, SF) = 0.5 \times Q(\sqrt{10^{SNR/10} \times 2^{SF+1}} - \sqrt{1.386 \times SF + 1.154})$$

18：
$$P_h(SNR, SF) = ((1-P_b)^4 + 3(1-P_b)^7 P_b)^{\lceil L_h/4SF \rceil}$$

19-23：
$$P_p(SNR, SF) = \begin{cases} (1-P_b)^{\lceil \frac{L_h}{SF} \rceil}, CR = 1,2 \\ ((1-P_b)^4 + 3(1-P_b)^{3+CR} P_b)^{\lceil \frac{L_h}{4SF} \rceil}, CR = 3,4 \end{cases}$$

24-25：
$$P_{preamble} = P_b(SNR, SF + log_2(n + 4.25))$$

26：
$$PDR(SNR, SF) = P_{preamble} \times P_h \times P_p$$

27：
$$EE(TP, SF) = \frac{DR(SF) \times PDR(TP, SF)}{TP}$$

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05

评估

EVALUATION

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实现与实验设置

节点：SX1276，SF: 12，TP level: 0；室外节点7个，室内节点4个
网关：SX1301，位于四层楼顶

评估EE Prediction Model (GetEE function)

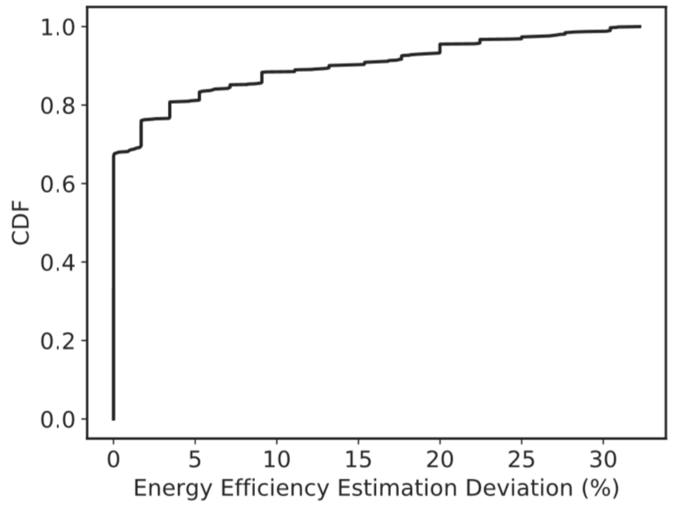

Fig. 9: Cumulative distribution of the energy efficiency estimation deviation.

Close to ground truth

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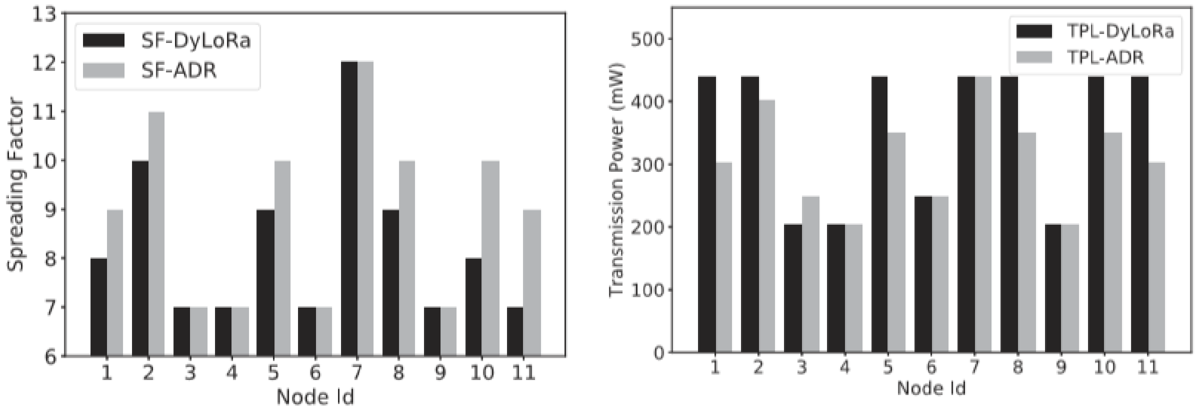
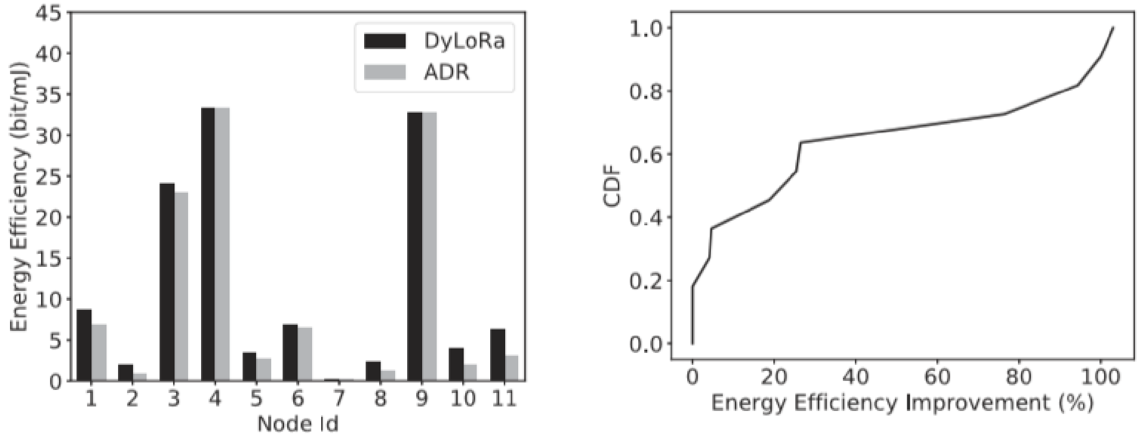
与ADR算法的比较



a) Spreading factor settings. b) Transmission power settings.

Fig. 10: Selected spreading factors and transmission power levels of the 11 nodes. Figure a shows the spreading factor settings of DyLoRa and ADR on each node. Figure b compares the transmission power settings of each node under DyLoRa and ADR.



a) Energy Efficiency Comparison. b) Energy Efficiency Improvement.

Fig. 11: Energy efficiency comparison between DyLoRa and ADR. Figure a shows the energy efficiencies of each node. Figure b shows the cumulative distribution function of DyLoRa's energy efficiency improvement compared with LoRaWAN ADR.

Lower SF   Higher TP   Higher EE   Great Improvement

EVALUATION

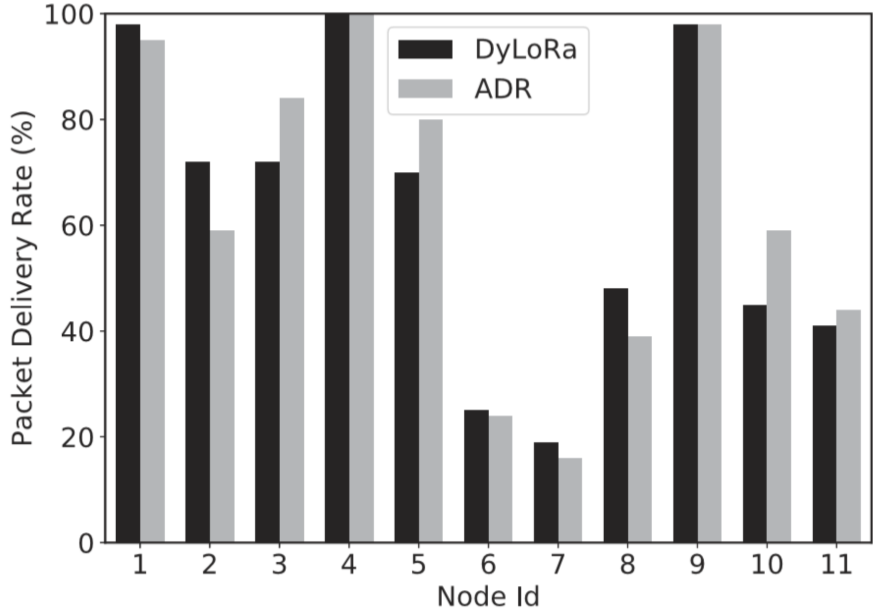


Fig. 12: Packet delivery rate comparison between the energy efficiencies of DyLoRa and ADR's parameter settings on each node.

Little PDR Sacrifice

06

结论

CONCLUSION

DyLoRa：动态LoRa传输控制系统，以优化能源效率

目标：填补ADR和最佳解决方案之间的能源效率差距

方法：①建立不同传输参数（包括TP、SF与SNR）下的能量效率模型
②通过非常稀疏的LoRa数据流量导出最佳能源效率的参数设置

结论：评估结果表明DyLoRa对比ADR能够将能量效率提高许多

感谢聆听

Thanks For Listening

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