Fragmentation and Forward Error Correction for LoRaWAN small Maximum Transmit Unit networks

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Low Power Wide Area Networks (LPWAN) :

Wireless cellular networks

- Low energy consumption: θ(10 years) battery autonomy.
- Low throughput: θ(10Kbps).
- Long range: θ(10km).
- Huge capacity: θ(1000 nodes) connected to a single gateway.

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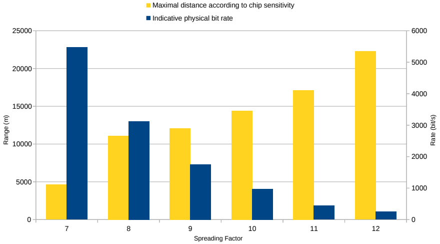
Packet Error Rate (PER) in wireless networks :

- Path Loss.
- Interferences and ambient noise.
- Collisions.

LoRa: Physical layer



- Chirp Spread Spectrum based modulation.
- 6 Spreading Factors (SF).
- SF are orthogonal.

⇒ Long range communication.
⇒ Noise resilient.
⇒ Multiples sub-channel.

Estimation with Friis :
$G_T G_R (\frac{\lambda}{4\pi R})^a = \frac{P_R}{P_T}$
with classic parameters for the target hardware [1].

[1] Antenna gain: $G_T, G_R = 1$; a Path Loss Exponent 2.64, transmitted power $P_T = 14dBm$, distance R, λ wavelength at 868MHz, Semtech LoRa™ SX1272/73 datasheet.

LoRa for LPWAN: LoRaWAN^{TM}

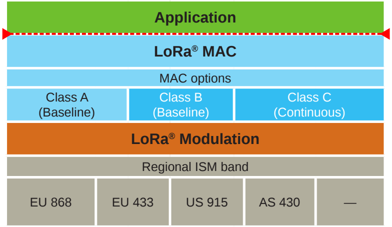


Figure: LoRaWAN^{TM} protocol stack.[1]

- Cellular architecture.
- Uplink oriented: from nodes to network server (NS).
- Asynchronous.
- ISM band.

[1] https://www.lora-alliance.org/portals/0/documents/whitepapers/LoRaWAN101.pdf

LoRaWAN™ Maximum Transmit Unit (MTU)

Table: Application payload (without any optional fields in the header) for the minimum and maximum DR in various bands[2].

Band	Maximum payload size (bytes)	
	Min DR	Max DR
EU863-870	51	242
US902-928	**11**	242
CN779-787	51	242
EU433	51	242
AU915-928	11	242
CN470-510	51	242
AS923	19	**250**
KR920-923	51	242
IN865-867	51	242
RU864-870	51	242

- ISM duty cycling regulation.
- Time On Air is SF dependant.
- Piggybacked LoRaMAC commands.

[2] LoRa Alliance Technical Committee Regional Parameters Workgroup. Lorawan 1.1 regional parameters. Technical report, LoRa Alliance, 2018.

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⇒ **Fragmentation.**

⇒ **Increases losses.**

Ex: With payload fragmented in 10 pieces over a 10% i.i.d erasures channel, less than 35% of the data can be delivered.

[2] LoRa Alliance Technical Committee Regional Parameters Workgroup. Lorawan 1.1 regional parameters. Technical report, LoRa Alliance, 2018.

LoRaWAN^{TM} reliability

To improve Data Delivery Rate (DDR):

- Increase Transmit Power (TxP).
- Increase SF.
- Systematic retransmissions (NBTRANS) : DDR $= 1 - (PER)^n$; Time On Air (TOA) $\times n$.
- Automatic Repeat reQuest (ARQ).

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Adaptive Data Rate (ADR)

- Dynamically adapts the transmissions parameters (TxP, SF, NBTRANS).

Problematic:

- How to decorrelate applicative-MTU and physical-MTU ?
- How to provide (very) high Data Delivery Rate ?

LoRa Fragmentation and Forward Error Correction

LoRaFFEC, a protocol to combine :

- Fragmentation
- Forward Error Correction

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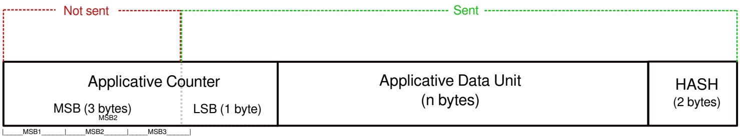
Sub-layers:

- Integrity.
- Fragmentation.
- Erasure Correction.

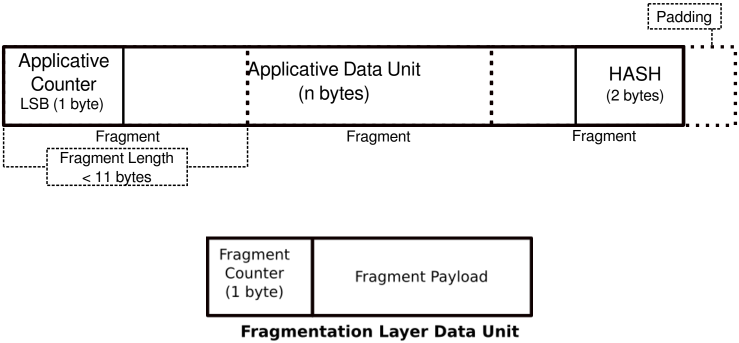
LoRaFFEC protocol

Integrity sub-layer:



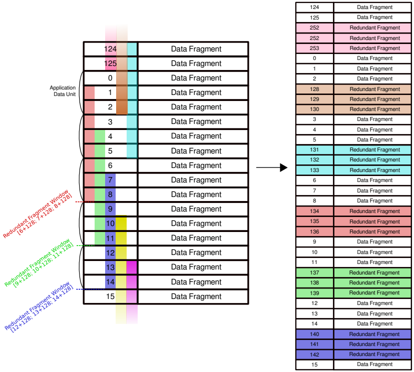
LoRaFFEC protocol

Fragmentation sub-layer:



LoRaFFEC protocol

Erasure Correction sub-layer[3]:



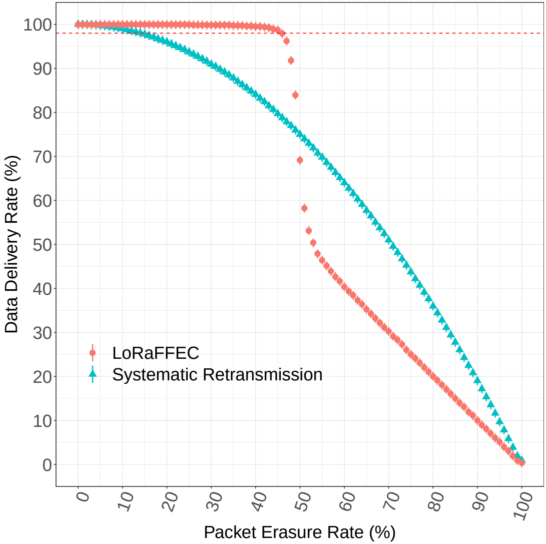
- Pseudo-random linear combinations.
- Coding Rate $= 1/2$.
- Resolved by Gaussian elimination.
- Parameters:
  - Window Length (WL).
  - Redundancy Density (RD).
  - Decoding Depth (DD).
- Decoding complexity : $O(w^2 \times DD)$.

[3] Marcelis, Paul J and Rao, Vijay S and Prasad, R Venkatesha. DaRe: Data recovery through application layer coding for LoRaWAN. In Internet-of-Things Design and Implementation (IoTDI), 2017 IEEE/ACM Second International Conference on, pages 97?108. IEEE, 2017.

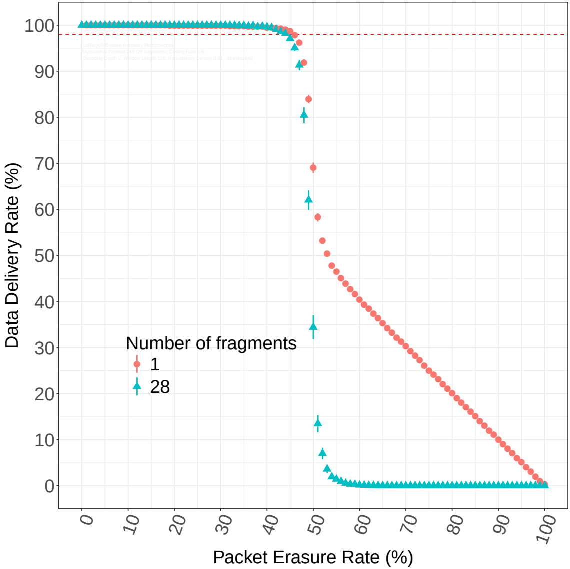
LoRaFFEC performances simulation

- Erasure channel
- Independant and identically distributed (iid) erasures
- 1000 Application Data Unit transmissions / experiment
- 95% confidence interval

DDR [WL=128; RD=0.6; DD=2]



With fragmentation [WL=128; DD=2; RD=0.61]



Conclusion LoRaFFEC

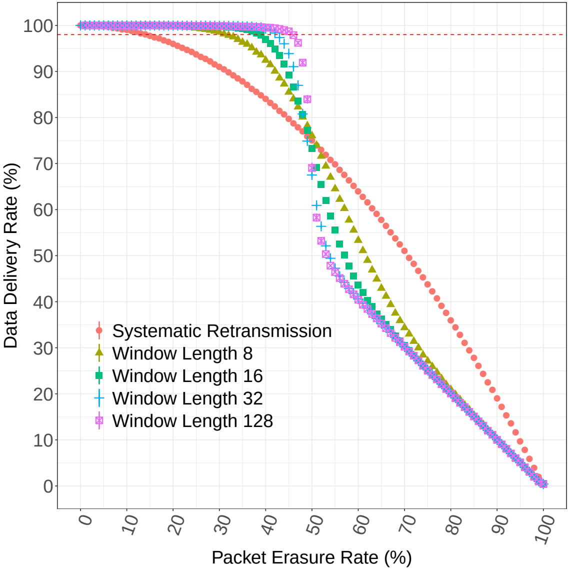
- **Combined fragmentation and application-level error correction.**
- **Data delivery rate (DDR) >98% up to 40% PER channels.**

Further work :

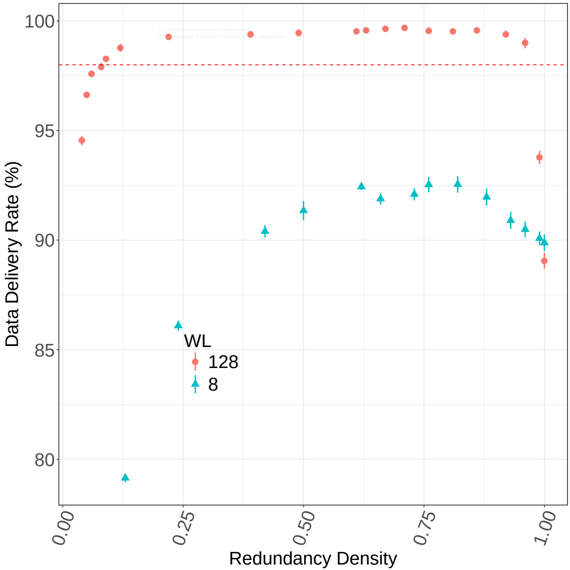
- Loosen LoRa™ physical parameters.
- Improve channel characterization and quality estimation.
- LoRaFFEC incorporated into ADR will improve network capacity and reliability.

THANKS

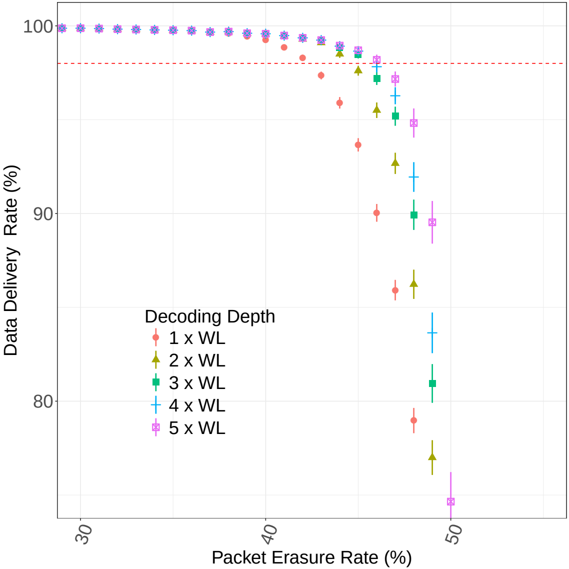
Window Length [DD=2; RD=0.61]



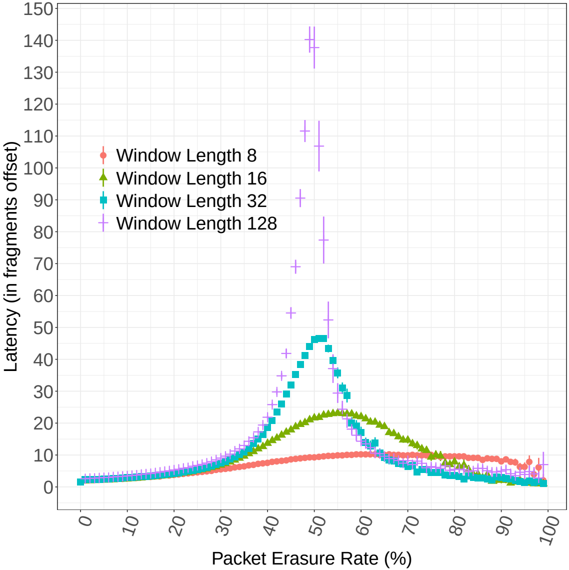
Redundancy Density [DD=2] PER=40%



Decoding Depth [WL=128; RD=0.61]



Latency [WL=128; DD=2; RD=0.61]



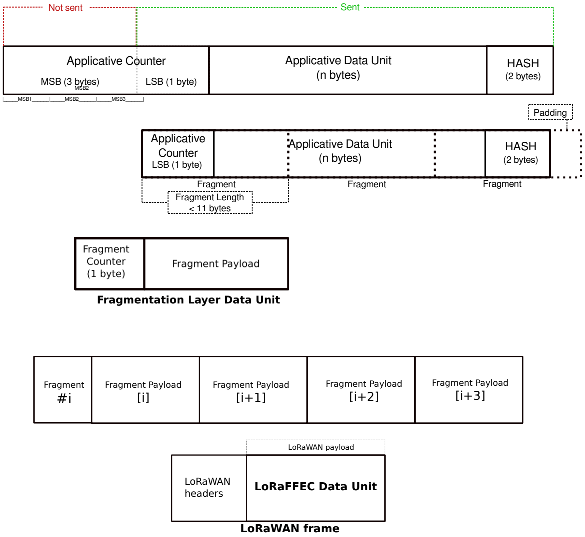
LoRaFFEC protocol

Services:

- Fragmentation
- Erasure Correction

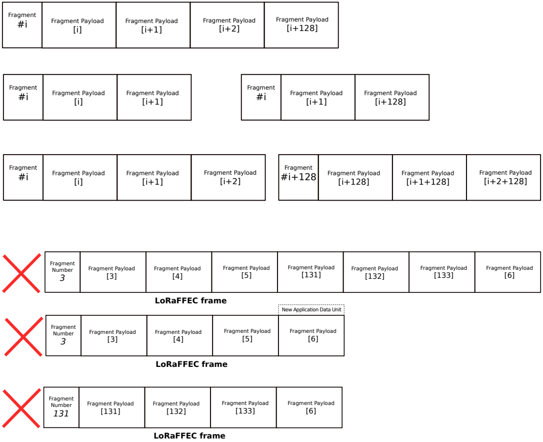
Protocol overhead:

- 1 byte applicative counter / applicative data unit (ADU)
- 2 bytes hash / ADU
- 1 byte fragment counter / LoRa^{TM} frame (physical)



LoRaFFEC protocol

Fragments aggregation in LoRaWAN^{TM} frame:



Reliability in LoRaWAN™

Systematic Repetition (SR) of the frames

- each frame is repeated *n* times
  ⇒ PDR $= 1 - (PER)^n$.
  ⇒ Time On Air (ToA) = ToA[uplink]$\times n$.

Automatic Repeat reQuest (ARQ)

- Uplink frames marked as *confirmed*
- Re-emitted in absence of downlink acknowledgement.
  ⇒ Overload of the gateways, blind period.
  ⇒ ToA = ToA[uplink] + ToA[acknowledgement].

At the physical layer: Adaptive Data Rate (ADR) protocol

⇒ Dynamically adapts SF, TxP...
⇒ Driven jointly by the network server and the node.
⇒ Rely on channel estimation (measured SNR, RSSI, ...)

⇒ Rely channel characterisation (Rayleigh fading, Gaussian noise, Log-normal path loss, ...)

State Of the Art: Forward Error Correction in LoRaWAN^{TM}

DaRe (Data Recovery)

- Pseudo random linear combination.
- Low latency.
- No downlinks required.
- Fixed redundancy rate.

CCARR (Channel Coding Adaptive Redundancy Rate) :

- Reed Solomon.
- High PDR.
- Dynamic redundancy rate.

[Marcelis, Paul J and Rao, Vijay S and Prasad, R Venkatesha. DaRe: Data recovery through application layer coding for LoRaWAN. In Internet-of-Things Design and Implementation (IoTDI), 2017 IEEE/ACM Second International Conference on, pages 97?108. IEEE, 2017.]
[U.Coutaud and B. Tourancheau. Channel Coding for Better QoS in LoRa Networks. In IEEE, editor, International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), pages 1–9, June 2018.]

State Of the Art: LoRaWAN^{TM} channel

- Bursty channel
- Log-normal fading with sd=7

P. J. Marcelis, V. Rao, and R. V. Prasad. Dare: Data recovery through application layer coding for lorawan. In Proceedings of the Second International Conference on Internet-of-Things Design and Implementation, pages 97–108. ACM, 2017.

- Highly variable PER

T. Ameloot, P. Van Torre, and H. Rogier. A compact low-power LoRa IoT sensor node with extended dynamic range for channel measurements. MDPI Sensors, 18(7):2137, 2018.

- Residual PER.

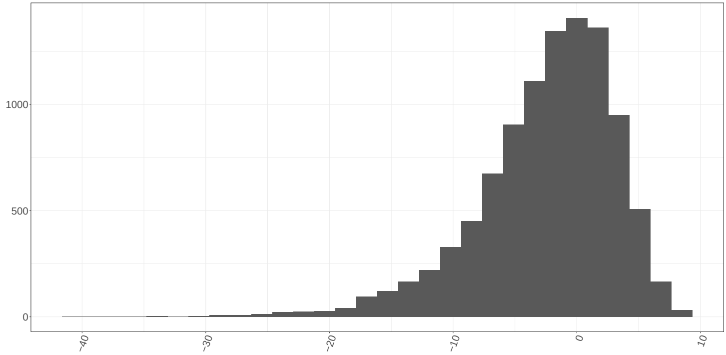
J. Petäjäjärvi, K. Mikhaylov, M. Hämäläinen, and J. Iinatti. Evaluation of LoRa LPWAN technology for remote health and wellbeing monitoring. In IEEE, editor, International Symposium on Medical Information and Communication Technology (ISMICT), pages 1–5, 2016.

J. Petajajarvi, K. Mikhaylov, A. Roivainen, T. Hanninen, and M. Pettissalo. On the coverage of LPWANs: range evaluation and channel attenuation model for LoRa technology. In IEEE, editor, International Conference on ITS Telecommunications (ITST), pages 55–59, 2015.

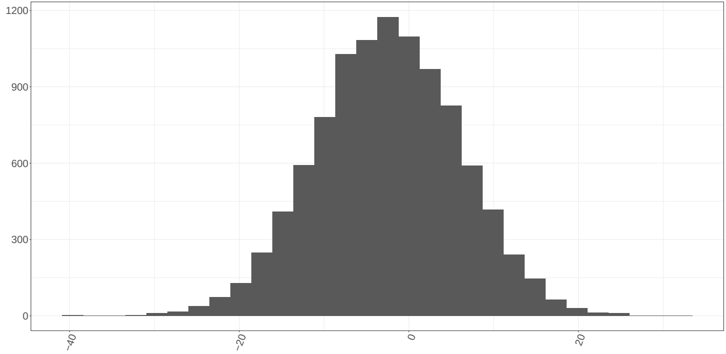
- Fast Rayleigh fading

T. Attia, M. Heusse, B. Tourancheau, and A. Duda. Experimental Characterization of Packet Reception Rate in LoRaWAN. In Rencontres Francophones sur la Conception de Protocoles, l'Évaluation de Performance et l'Expérimentation des Réseaux de Communication, editor, CoRes, Narbonne, France, June 2019. https://hal.archives-ouvertes.fr/CORES2019/hal-02129199v1.

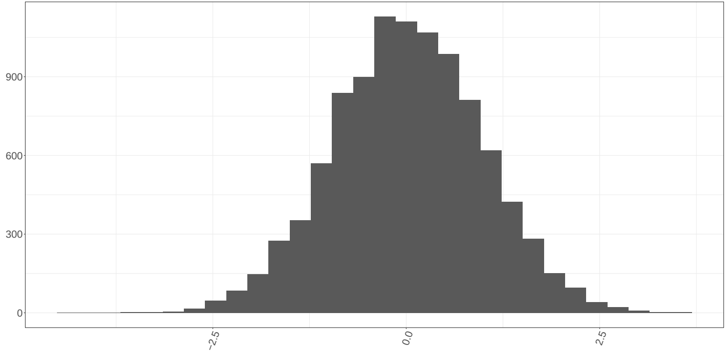
Exponential distribution (dB)



Log-normal distribution m=0.56 sd=7.11 (dB)



Log-normal distribution sd=1.25 (dB)



State Of the Art: Forward Error Correction in Wireless Networks

- Y.Birk and Y.Keren. Judicious use of redundant transmissions in multichannel aloha networks with deadlines. IEEE, 1999.
- Ender Ayanoglu, Pramod Pancha, Amy R Reibman, and Shilpa Talwar. Forward error control for mpeg-2 video transport in a wireless atm lan. Mobile Networks and Applications, 1996.
- C. E. Luna, Y. Eisenberg, R. Berry, T. N. Pappas, and A. K. Katsaggelos. Joint source coding and data rate adaptation for energy efficient wireless video streaming. IEEE Journal on Selected Areas in Communications, Dec 2003.

LoRaWAN^{TM} network architecture