LoRaWAN Optimized Transmission Interval Analysis

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***Abstract*—This paper introduces a LoRaWAN optimized data transmission interval analysis. LoRa is a popular low power wide area (LPWA) communication technology which targets sensor based internet of things applications in regional, national or global networks. LoRa comes with low power and long range communication promises with an patented modulation technology. Due to it's hardware limitations some discussions exist both in academic researches and industrial applications. This research build over retransmission analysis study and tend to get a feasibility work for target LoRaWAN project. To answer these questions a discrete event simulator LoRaSim used.**

I. Introduction

Mobility, connectivity and accessibility becomes a need for everyone and everything in our era. With GSM and wired/wireless internet networks humans have already reached that state. Now due to cutting edge technologies, things are getting closer the same state. Most people lives in close area, on the other hand things ,want to be connected, may spread over wide areas. Such internet of things problem solving rely on low-power wide-area network (LPWAN). Common LPWAN technologies are LoRa, Sigfox, Telensa, NB-IoT, Nwave, Weightless. LoRa is chip spread spectrum based, others are ultra narrow band examples. LoRa is the most deployed LPWAN technology which provides scalable, long range low power communication. LoRaWAN is defined as wide area network of LoRa devices. LoRa uses a modulation technique which property of Semtech Corporation. LoRaWAN has a low bit rate because of long-range and low-power behavior , thus appropriate for low frequency, small data capacity, periodic sensor reading telemetry systems. To configure well balanced overall LoRaWAN system LoRa devices has configuration parameters which are transmission power (TP), carrier frequency (CF), spreading factor (SF), bandwidth (BW), coding rate (CR). These parameters are related with hardware and modulation technique features. There are some good researches to optimize these parameters for scalable networks. Beside these general optimized parameter configurations, also algorithm designs and application specific simulated configurations may apply for target network system. This study focuses on optimizing packet transmission issue on packet-loss system which is common in large scaled networks. With a discrete event simulation tool LoRaSim packet transmission interval parameter analysis will be shown.

II. LoRa / LoRaWAN

LoRa is a spread spectrum modulation technique which is developed by Semtech. Its technique derived from Chirp Spread Spectrum [1]. Devices which uses LoRa modulation techniques, called LoRa devices in general system. These devices can be a node or gateway. LoRa devices operates blow noise floor with 20 dBm to match with doppler resistance. LoRa devices has a large link budget and processing gain to communicate in long range with low power. LoRa transceivers can use run-time configurable transmission parameters that used to optimize network power, transmission time, range or prevent form collisions and inter-network interference [2]. LoRa end devices has three different types (Class A/B/C) to meet different application purposes.

LoRaWAN is a LPWAN technology which is network of LoRa devices and network servers. It has a one hop communication with star topology. In technical, it is medium access protocol for wide area networks and it is substitution of second and third level of OSI network model [4] . It is an open standard and developed by LoRa Alliance.

A. Transmission Options

Transmission Power (TP) is one of the configurable parameter for LoRa transceivers. However it can be adjusted from -4dBm to 20 dBm theoretically, due to hardware limitations it can be operate from to 2 dBm to 20 dBm with 1 dBm stepping.

Carrier Frequency (CF) CF is the centre frequency, ?t can be adjusted 137 MHz to 1020 MHz in 61 Hz steps but may be limited from 860MHz to 1020 MHz in a real implementation [1].

Spreading Factor (SF) is the ratio between the symbol rate and chip rate. It can be adjusted from 6 to 12 and this numbers determines how many chips are encoded in each symbol as a power of two. SF is a trade off between signal to noise ratio (SNR)and transmission rate. Higher SF proportionally higher SNR affects the receiver sensitive and range of signal. Transmission rate, is inversely related with SF, affects transmission durations and energy consumption. SFs in LoRa are orthogonal , which means concurrent transmissions with different SF do not interfere and can be decoded properly [2].

Bandwidth (BW) can be set from 7.8 kHz to 500 kHz, but general bandwidth usages are 125 kHz,250 kHz and 500kHz in LoRaWAN examples.

Coding Rate (CR) is the amount of forward error correction (FEC) that used by the LoRa modem to compensate burst of interference. Coding rate can be chosen as 4/5, 4/6, 4/7 or 4/8. A higher CR offers more protection controversially increases on-air time. Two devices can communicate with different CR, it has a separate header than payload data.

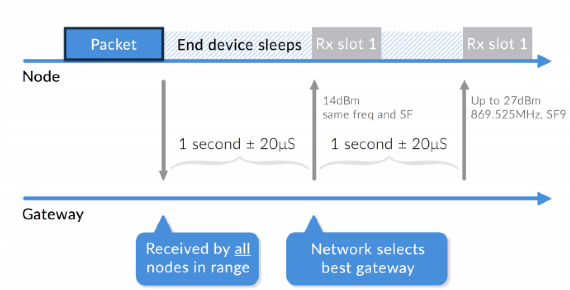

Fig. 1. LoRa Class A Device [4]

B. Device Classes

LoRaWAN supports three different types of end devices which can be communicated with same gateway device. These classification performed because of application differentiations. All these three classes have bidirectional communication but differs in downlink features.

- Class A devices can be sent data to gateway any time. When send a data to network, then device opens two receive windows with different delay timings. If an acknowledge could not received in these two section, there will be any other opportunity to receive ACK until the the next uplink transmission from the device. Another tricky point is server can only send ACK to first window or second window, double replies will be useless. Class A device transmission scheme can be seen at figure: 1.
- Class B devices has scheduled receive windows for downlink.
- Class C devices have always open downlink window unless transmission times. Class C devices has a low-latency features with high power consumption.

Although a network configuration which deploys top of acknowledgement messages controlling, more secure for many IoT applications with functions handshaking, network joining, security isssues [2],it causes huge bidirectional data transmission. A network with Class A devices more scalable due its limited downlink feature. Downlink limitation enables the traffic for more transmission or same amount transmission from more nodes. This work focuses on Class A communication optimization on configurable network to choose best parameters with reliable and lightweight network. Scalability of network is not belong transmitter parameters, also it can optimized with downlink traffic feature and retransmission attempts which is directly related with device classes.

C. Adaptive Data Rate

In LoRaWAN expectation is effective communication with numerous inexpensive devices. Inexpensive device and maintenance requires clever decision on configurations. Control transmission parameter of LoRa devices on modulation features such as (CF,BW,CR) and output power makes a difference in sustainability and reliability. To ensure with this optimization Adaptive Data Rate defined. Adaptive Data Rate (ADR) is a mechanism for optimizing data rates, airtime and energy consumption in the network. Fixed nodes are appropriate for ADR and, nodes should make ADR decision. Most common ADR algorithm is can be seen at figure: 2.

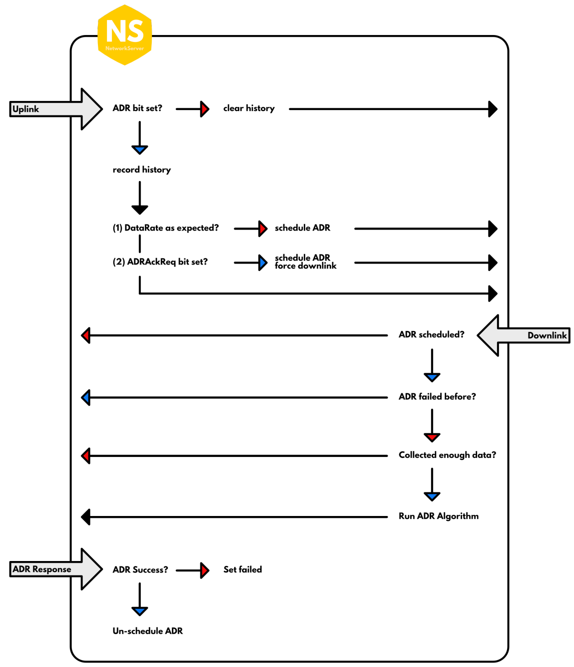

Fig. 2. LoRaWAN ADR [5]

D. Fair Access Policy

According to The Things Network(TTN) Fair Access Policy, each device's uplink on air time should be average 30 seconds per day and at most 10 downlink message including transmitted packet ACKs. Fair Access Policy also says that, application payload should be 12bytes and there should be a wait time between concurrent message transmits. These numbers are stated according the LoRa device technical features and LoRaWAN operability regulations. As an example for European 863-870MHz bands duty cycle restricted with %1 and application payload can be 51 bytes for slowest data rate and 222bytes for fastest data rate. Beside the application payload LoRaWAN protocol adds 13byte into relevant packet. The reason of duty cycle and packet size limitation is, in an open network when end devices send their messages to unknown base station, in a such case base station is not closer the node, then packet on-air time will be increase. Because of increasing on-air time, the node should send messages with slower data rates to ensure data can be received. And due to on air time node device could not send new data packet for a time which affects the duty cycle limitation. For example if a node send a packet which has 0.5 seconds on-air time then it should have a busy-wait state for 49.5 seconds. Under this circumstance a LoRaWAN device could have a 20 uplink messages per day with SF12, and 500 uplink messages/per day with SF7. When considering the downlink procedure, application should not need downlink for every message.

III. Proposal and Implementation

We know that there are some fundamental parameters for network optimization. ADR and other device configuration re-

	no-collision check					
	Optimized TP			Non-Optimized TP		
Nodes	3avg	5avg	8avg	3avg	5avg	8avg
50	0.48	0.50	0.48	0.45	0.45	0.46
100	0.33	0.31	0.30	0.31	0.33	0.34
200	0.17	0.19	0.19	0.22	0.20	0.20
500	0.06	0.06	0.06	0.05	0.06	0.06

Fig. 3. Test Data without Collision Check Feature

	collision check					
	Optimized TP			Non-Optimized TP		
Nodes	3avg	5avg	8avg	3avg	5avg	8avg
50	0.55	0.53	0.54	0.5	0.59	0.56
100	0.40	0.39	0.37	0.36	0.36	0.38
200	0.23	0.24	0.25	0.27	0.25	0.26
500	0.09	0.10	0.11	0.10	0.10	0.10

Fig. 4. Test Data with Collision Check Feature

lated parameters gives some flexibility. Beside these MAC configurations, hardware related software optimization decision could affect system reliability and cost. This study states that retransmission and transmission has big impact on this issue. Several test scenarios considered to examine data transmission analysis. Some of these scenarios available with a discrete event simulator LoRaSim which is presented in [1]. This simulator has capability to test network with variety device configuration and network scalability parameters. It has only one directional (uplink) message feature and does not have MAC layer implementation yet. Although some weak features of LoRaSim, some of target scenario could be performed.

As a first stage of this research study, packet retransmission analysis performed. Thus a LoRaWAN system has limited data flow both uplink and downlink, and because of ClassA devices' downlink time limitations retransmission of each data packet considered. Network has n nodes and x retransmission for each application data send with no acknowledgements then simulator gives data extraction rate (DERx). The weak point of this simulation is every simulation run will simulate only ith data packet. So for data packet i+1 simulation should be rerun, but for feasibility researches one packet case simulation will proof average idea. Simulation uses proven configuration parameters from [1] table 2. [1] states that SN3 configuration is most common and optimized LoRaWAN configuration. These parameter values are TP:14, 868, SF:12, BW:125, CR:4/5 with 20byte payload. Simulation results with these parameter too far from optimistic results expected on behalf of prior researches [1], [2]. Actual expectation is getting higher than 0.9 DER with some NEC output and comparing them. Current LoRaSim outputs does not give power related outputs and DER rate really low on such scenario. Test scenario parameters are number of node, 3-5-8 average send for a single data package, output power optimization and collision check feature. The test outputs are given in figure: 3, and figure: 4.

As expected result does not match simulation results in scenario 1, transmission interval approach re-considered. As a second scenario a remote-sensor metering application considered as a target application. After the researches about limitations and transmission characteristic, TTN's "Fair Access Policy" based scenario 2 is set as:

- Three different time zone exists in receipting procedure (morning-day-night) , so that node device should send data according this feature. Because of time zones, data recovery cannot be performed.
- SN3 configuration [1] will used, to used optimized long-range communication.
- Different time intervals will be tested with limitation at most 20 message per day for each end node.
- Test set which has DER under %90 will be classified as unadvisable.

Tests sets can be seen in table 5 for 1 day long data transmission with 50 end nodes and table 6 30 day day long for same configuration. According to these result both transmission interval and day long changing affects the power consumption perpendicularly. This is a simple image for general system architecture performance.

The actual examination for system is about how the transmission intervals will affect the average DER and NEC. Expectations are decreasing DER and increasing NEC due to the decreasing transmission interval. Test results of different number of node usage and in different sending intervals given in table 7 and table 8. The numbers in these tables extract a rule which is increasing time interval (so decreasing number transmission) for same number nodes , gives better DERs. Also number of nodes another parameter on DERs.

Transmission Interval	#Nodes	#Collisions	#Transmissions	OverallEnergy (24hr)
1hr	50	46	1197	208,39
1,5hr	50	14	807	140,50
2hr	50	16	559	97,32
3hr	50	2	384	66,85
4hr	50	0	331	57,63
6hr	50	2	204	35,52
8hr	50	2	153	26,64

Fig. 5. 1 Day Long Test Results

Transmission Interval	#Nodes	#Collisions	#Transmissions	OverallEnergy (30day)
1hr	50	1227	35939	6256,85
1,5hr	50	585	24242	4220,44
2hr	50	625	24065	4189,63
3hr	50	323	18027	3138,44
4hr	50	170	11902	2072,1
6hr	50	84	8939	1556,25
8hr	50	38	6003	1045,1

Fig. 6. 30 Day Long Test Results

Transmission Interval	#Nodes	#Collisions	#Transmissions	OveralEnergy (24hr)	DER
1hr	50	37,2	1218	212,052	0,969452
1hr	100	161,2	2389,2	415,952	0,932524
1hr	500	3672,6	11971,2	2084,142	0,693196
1hr	1000	12277	23858	4153,59	0,48541

Transmission Interval	#Nodes	#Collisions	#Transmissions	OveralEnergy (24hr)	DER
1,5hr	50	18,2	1218	212,052	0,977344
1,5hr	100	84,6	2389,2	415,952	0,94791
1,5hr	500	1671,2	11971,2	2084,142	0,790782
1,5hr	1000	6197,33333	16063,33333	2796,57	0,613907

Transmission Interval	#Nodes	#Collisions	#Transmissions	OveralEnergy (24hr)	DER
2hr	50	12,4	610,4	106,2682	0,97941
2hr	100	40,2	1220	212,396	0,965258
2hr	500	1009,4	5971,2	1039,564	0,83092
2hr	1000	3751,66667	12015,33333	2091,823333	0,68775

Transmission Interval	#Nodes	#Collisions	#Transmissions	OveralEnergy (24hr)	DER
3hr	50	4,8	398,8	69,4296	0,987974
3hr	100	20,4	796	212,396	0,965258
3hr	500	462,8	4004	697,104	0,83092
3hr	1000	1689	12015,33333	1370,836667	0,785423

Transmission Interval	#Nodes	#Collisions	#Transmissions	OveralEnergy (24hr)	DER
4hr	50	3,2	306,2	53,2654	0,989688
4hr	100	12,4	594,6	103,5172	0,979172
4hr	500	253,4	2955	514,4548	0,914212
4hr	1000	968,333333	5966	1038,658667	0,83779

Fig. 7. Interval and Node Number Changes Table1

Transmission Interval	#Nodes	#Collisions	#Transmissions	OveralEnergy (24hr)	DER
6hr	50	0,8	205,8	35,828	0,996028
6hr	100	4,4	396,2	68,982	0,990978
6hr	500	129,4	1988,4	346,1734	0,934876
6hr	1000	498,666667	3963	689,9433333	0,87414

Transmission Interval	#Nodes	#Collisions	#Transmissions	OveralEnergy (24hr)	DER
8hr	50	0	150,6	26,2189	1
8hr	100	4,4	310,8	54,10905	0,985976
8hr	500	56,4	1526	265,671084	0,962846
8hr	1000	276	3042,666667	529,71726	0,9092

Fig. 8. Interval and Node Number Changes Table2

IV. Conclusions

According to the LoRaSim simulation results an LoRaWAN application suggestion can be offer. For smart metering application, a design engineer can be decide many hardware depended parameters but the most important point of designing a LoRaWAN system is data need characteristics. Data handling ca be considered in two subsection. One of it partially depended with hardware. If hardware have a internal memory then it can store data and retrieve stored data, encapsulate as a one package in larger intervals. One other option is sending data in appropriate interval as original data. Also one option is due to probability of loss retransmission same data in a short interval however, test results show that it is inefficient way of data transmission and also it is not suggested by Fair Access Policy.

To clarify conclusions, an application may be designed as, 8 hour data transmit interval according to the receipting timings. All data includes its past days data within 20byte (sensors generally generates few bytes generally). Then application server resolves duplicate past data and actual data. If an crucial acknowledgment is need then send acknowledgment in right time with matches with classA device acknowledgment sections. Application server is the appropriate computing point for all these operations. Node computing units are just get raw data from sensor and pack data and send it. If this operation performs with 500 nodes per base station then system will have reasonable DER which is 0,96. All these are opinion according to the number not a exact rules. Design or feasibility engineer should examine exact system needs in real scenario but the limits can be found in this study's results.

Retransmision of same data is still be considered if system is not in very large area and does not contain massive number of nodes. However, re-transmission intervals should not be shorter than 16 minutes as stated both [1] and TTN's Fair Access Policy.

Last point on this study is LoRaSim. It is easy to use but not mature simulator. Some issues such as scalability, base station placement, end node distribution can be easily tested, however it does not support such features like bidirectional data transmission, different transmission interval assignments, payload variability etc.

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